Bio 11 Student Reference Guide

Prepared for

Kingsborough Learning Center

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Preface

This study guide is intended to be used as a supplement for lecture sessions, self study, and tutoring sessions. This guide is designed to provide background and basic explanations for complex topics. Do not attempt to use this guide as your sole source of information. Please remember that your professors will be creating assignments and tests based on the material they present, which may have some differences from the materials in this guide.

Introduction to Anatomy and Physiology

Biology is the study of living organisms. The aspect of biology we will be studying is **anatomy** and **physiology**. Anatomy is the study of the structure of living organisms, while physiology is the study of the functions of living organisms.

Key Concepts

Cell Theory

Cell theory is a major concept of biology which describes the basis and organization of life.
Cell theory states:

1. All living organisms are composed of one or more cells
2. The cell is the basic unit of structure and organizations in organisms
3. Cells are created by other cells

This means that the smallest living organisms are cells, while larger organisms are composed of groups of cells combined together, and that all organisms are created by other previously existing organisms.

Hierarchy of Complexity

The hierarchy of complexity describes how simpler structures can be combined in order to create more complex structures.
From the simplest levels to the most complex is as follows:

1. Chemical level of organization. This describes how atoms bond to form molecules, and molecules combine to form macromolecules
2. Cellular level of organization. This describes how cells are created by combining macromolecules to form organelles, and these organelles work together to form cells.
3. Tissue level of organization. This describes how groups of similar cells work together to perform jobs.
4. Organ level of organization. Organs are composed of groups of different tissues that complement each other in the performance of a task
5. Organ system level of organization. Organ systems are groups of organs that interact together to perform complex tasks.
6. Organism level of organization. Maintained by the function of all of the organ systems working together to maintain vital function

Characteristics of Life

As biology is the study of life, we need to define what qualifies as a living organism. To do this, we have a list of functions that need to be performed in order to qualify as life.

1. Organization. Living organisms are more organized than non-living materials, and will exhibit structure described by the hierarchy of organization.
2. Cellular composition. All living matter is composed of cells
3. Metabolism. Living organisms will take in chemicals from their environment and chemically alter them into forms suitable for their own use through the use of chemical reactions. Metabolism describes all of the chemical reactions that occur inside an organism
4. Responsiveness to environment/movement. This refers to the ability to sense changes in the environment and respond to those changes.
5. Homeostasis. Homeostasis is the ability to maintain a stable inner environment
6. Development. This describes how the organism will change over time over the lifetime of the organism
7. Reproduction. All living organisms can produce copies of themselves.
8. Evolution. Living organisms will have genetic change over a period of multiple generations in order to better suit their environment.

Some of these characteristics, especially metabolism, rely on outside sources of chemicals and supplies. Without these supplies, life cannot be supported.

Homeostasis

Homeostasis is the ability of an organism to maintain a stable internal environment. To perform this function, The organism needs to be able to sense changes, combine and process the information, and create changes in response to those changes.

- **Receptors** are structures that sense changes inside of an organism
- **Control centers** are structures that collect signals from the receptors, analyze the information, and then activate responses.
- **Effectors** are structures that produce changes inside the organism.

When describing the changes in the organism, we also have terminology to describe the changes inside the organism.

- **Stimulus** is the original change in condition in the organism that triggers the homeostatic response
- **Response** is the change in the organism that is caused by the organism due to the original stimulus.

Homeostasis is typically managed by **feedback loops**, a series of responses designed to compensate for changes caused by stimuli.

Negative Feedback

The most commonly used feedback mechanism is **negative feedback**, during which, the organism will create a response that is the opposite of the initial change, in order to “undo” the effects of that change. In negative feedback, the body will do the opposite of whatever the initial change was. Negative feedback is the main method for maintaining homeostasis.

Ex: if temperature decreases, the body will increase temperature by shivering.

Positive Feedback

When there is a stimulus that cannot be corrected by negative feedback, the organism will instead use positive feedback. Positive feedback involves a repetitive series of effects that will continue until homeostasis is restored. In positive feedback, each response will trigger the next response. Positive feedback is only rarely used in the body.

Examples of positive feedback:

- **Pregnancy**
  Once pregnancy occurs, it cannot be reversed. In order to return the body to a pre-pregnancy state, the fetus must be removed from the body.
  In order to do this, a series of contractions occurs in the uterus. Each contraction will cause the release of a hormone oxytocin, which will trigger further uterine contractions. The end result of the contractions will be the expulsion of the baby, returning the body to its original state.
- **Blood clotting**
  When a blood vessel is damaged, blood will escape until the hole in the vessel is sealed. In order to seal the hole, platelets will stick to the edge of the torn blood vessels. This in turn causes additional platelets to stick to the prior platelets, continuing until the hole in the blood vessel is sealed.

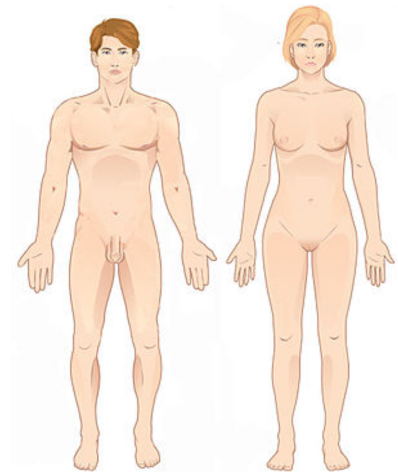
Anatomical Terminology

In anatomy and physiology there are a series of specialized terminology that is used for describing locations and positions. These terms allow for accurate transmission of information between users.

Anatomic Position

Anatomic position refers to a standardized position of the human body in order to allow for a standard frame of reference.

Anatomic position is a stance where a person stands up, with arms and legs slightly spread. The feet are flat on the floor, and the palms of the hands are facing forward.



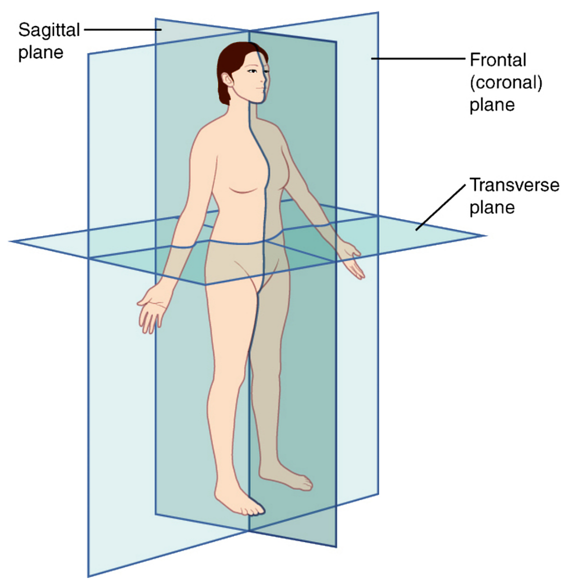
Anatomic Planes

Anatomic planes are used to describe the direction that you are observing a person or image from.

The **sagittal plane** passes vertically through the body from the front to the rear, separating it into a left and right view.

The **transverse plane** passes horizontally through the body, separating it into a top and bottom view.

The **frontal plane** passes vertically through the body, from the side, separating it into a front and back view



Directional Terms

When describing positions in the body, we use a series of terms that describe the location of one position in relation to another. These terms are typically paired in opposing pairs. The use of unique terminology allows for precise description of relative location of an anatomic structure.

- **Posterior** - behind
- **Anterior** - in front of
- **Superior** - above
- **Inferior** - below
- **Deep** - farther into the body
- **Superficial**- closer to the surface of the body
- **Medial** - toward the midline of the body
- **Lateral** - toward the edges of the body

  The following terms are **only used when describing the limbs**
- **Proximal** - closer to the body
- **Distal**- farther away from the body

When using these terms, there is a standard format that tends to get used:

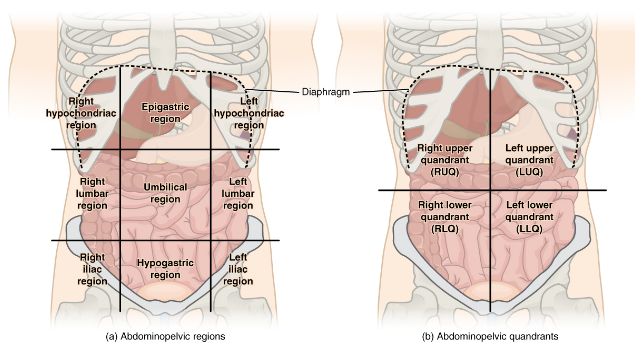
"The **(Body Part)** is **(Directional Term)** to the **(body part)"**

When practicing this, form the sentence using standard English terms, then insert the names of the body parts and the directional term from the list above.

Ex: "The **nose** is **above** the **mouth**" becomes "The **nose** is **superior** to the **mouth**"

Quadrants of the Abdomen

The abdomen has numerous organs within a relatively small area. In order to identify regions within the abdomen, we describe the abdomen as having either four quadrants, or nine regions.



In the four quadrant system, an imaginary line runs horizontally and vertically through the belly button (umbilicus), separating the abdomen into a right, left, upper, and lower quadrant.

In the nine quadrant system, two lines are run vertically from the middle of the collar bones (midclavicular line), and two are run horizontally from the lower ribs and the hips, forming nine regions.

Upper regions: left/right **hypochondriac**, **epigastric** region

Middle regions: left/right **lumbar** regions, **umbilical** region

Lower regions: left/right **iliac** regions, **hypogastric** region

Body Cavities

The body cavities are spaces within the body lined by membranes. Each cavity has a set of two cavities, the parietal membrane which lines the walls of the body cavity, and the visceral membrane which will line the organs within the cavity. The cavities will contain and protect the major organs of the body.

Ventral Cavities

Thoracic Cavity - major cavity of the chest, contains pleural, pericardial, and mediastinal cavities

- Pleural cavities - lateral cavities inside thoracic cavity, holds the lungs
- Pericardial cavity - medial cavity inside thoracic cavity, contains the heart
- Mediastinal cavity - located superior to pericardial cavity, contains the major blood vessels of the chest

Abdominopelvic Cavity - Inferior to the thoracic cavity, contains the abdominal and pelvic cavities

- Abdominal cavity - bounded by the diaphragm on its superior margin, contains the organs of the digestive system
- Pelvic cavity - inferior to the abdominal cavity, contains the organs of the reproductive system, and some organs of the urinary system.

Dorsal Cavities

Cranial Cavity - Located inside of the skull, contains the brain.
Vertebral Cavity - Located inside of the vertebral column, contains the spinal cord.

Organ Systems

1. **Integumentary system** - provides protection from infection and damage, prevents loss of water, helps control body temperature, and other functions. Major organ: Skin
2. **Skeletal system** - provides structure, shape, support, and allows movement. Site of blood cell production, primary site of calcium storage. Major organ: Bones
3. **Muscular system** - provides movement and temperature regulation. Major organ: Skeletal muscles
4. **Nervous system** - provides control of the body using electrical signals. Major organs: Brain and spinal cord.
5. **Endocrine system** - provides control of the body using hormones. Major organs: Endocrine glands throughout the body
6. **Digestive system** - breaks down and absorbs nutrients from food. Major organs: Stomach, Intestines
7. **Cardiovascular system** - transports oxygen and nutrients in the body. Major organs: Heart and blood vessels.
8. **Lymphatic system** - provides protection from infection. Major organs: Lymph nodes

9. **Respiratory system** - brings oxygen from air into blood, and removes carbon dioxide from the blood into the air. Helps control the levels of acid in the body. Major organs: Lungs
10. **Urinary system** - removes wastes from blood, produces urine, helps control the amount of acid in the body. Major organs: Kidneys
11. **Reproductive system** - creates hormones that cause physical differences that occur in puberty, create sex cells that allow for reproduction. Major organs: Gonads

Chemical Level of Organization

Metric Units

The metric system is a system of measurement that uses base units and factors those units by powers of 10. This allows for easier conversion between units of different sizes compared to the english unit system (feet, yard, mile, etc). The metric bases that are most commonly used are the **meter**, which is a unit of distance, the **liter**, which is a unit of volume (space), and the **gram**, which is a unit of mass (weight).

Metric Conversion

A metric number has two parts, the numeral and the prefix before the unit. Metric prefixes represent a factor that you are multiplying the number by,

When converting between prefixes, you need to multiply the number by the difference in the two factors.

Using the powers associated with the prefixes can make this process easier. In **scientific notation** you are multiplying a number by the power of 10 to a number. This number represents the number of times you are moving a decimal point, positive moving to the right, and negative to the left..
Ex: $1 \times 10^2 = 100$, or moving the decimal right 2 places

Prefix	Symbol	Factor	Power
mega	M	1 000 000	10^6
kilo	k	1 000	10^3
hecto	h	100	10^2
deca	da	10	10^1
(none)	(none)	1	10^0
deci	d	0.1	10^{-1}
centi	c	0.01	10^{-2}
milli	m	0.001	10^{-3}
micro	μ	0.000 001	10^{-6}
nano	n	0.000 000 001	10^{-9}

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A simplified way to change prefixes is to take the exponent of the original prefix, and subtract the exponent of the final prefix from it. This will give you the difference in power between the two units. Using this, you move the decimal of the number right if the exponent is positive, or left if negative, that many places in order to complete the conversion
Ex: 10km → __Dm
k = 10^3 D = 10^1 → 3 - 1 = 2, move decimal right 2 places 10.km → 1000.Dm

Ex: 147mg → __g
m= 10^{-3} no prefix = 10^{0} → -3 - 0 = -3, move left 3 places
147mg → 0.147g

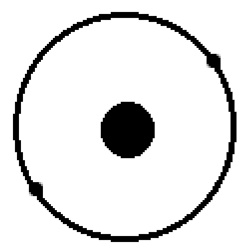
Atoms

Atoms are the smallest unique building blocks of matter. Atoms are composed of smaller particles, **protons**, **neutrons**, and **electrons**. Depending on the number of protons, neutrons, and electrons used in each atom, they will have different properties. Each of these unique atoms is referred to as an **element**.

Each of the particles that makes up the atom have their own unique properties.
Protons: Have a positive charge, and a mass of slightly over 1 AMU (atomic mass unit)
Neutrons: Have no charge, and a mass of slightly over 1 AMU
Electrons: Have a negative charge, and a mass of close to 0 AMU

Atomic Structure

When describing an atom, we typically describe the atom using the planetary model. This model breaks the atom into two main parts, the **nucleus**, located in the center of the atom, and the **electron orbits**, which surround the nucleus in a series of rings.

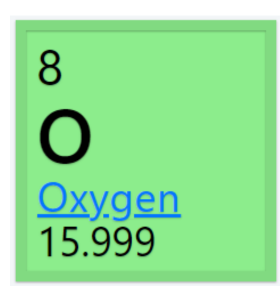


The nucleus contains the protons and neutrons of the atom, and is isolated from its surroundings by the electron orbits. Since all of the protons and neutrons are in the nucleus, almost all of the atom's mass is found in the nucleus.

The electrons will constantly circle the nucleus at high speed. Because of the attraction between positive and negative charges, the electrons are not able to leave the electron orbit, unless they receive energy from an outside source. The more energy an electron has, the farther out it will be from the nucleus. Due to different amounts of energy, there may be electrons occupying several orbits around the nucleus. The electrons in the outermost shell, the **valence electrons**, are able to interact with surrounding atoms. Each atom can have up to eight valence electrons.

Elements

The elements are the unique configurations of atoms. There are 118 known elements, some of which are man made, and are not naturally occurring. These elements are recorded on the **periodic table of the elements**, which lists each element's atomic number, name, and atomic mass. On the periodic table, the atomic number represents the number of protons in the atom. This also allows you to calculate the number of electrons, since in order to maintain a



balanced number of charges, you will have the same number of protons and electrons. Finally, the atomic mass represents the number of protons+neutrons, so by subtracting the atomic number from the atomic mass, you can calculate the number of neutrons

Ions and Isotopes

You will sometimes see atoms whose components are slightly different than those of the standard elements. The two most common variations are **ions** and **isotopes**.

An ion is an atom that has a different number of electrons than the standard element. This occurs when an atom gains or loses electrons to the surrounding atoms. If an atom loses electrons, it has lost negative charges, becoming positively charged. These positively charged ions are called **cations**.
If an atom gains electrons, it has gained additional negative charges, becoming negatively charged. These negatively charged ions are called **anions**.

An isotope is an atom that has a different number of neutrons than a standard element. This creates an atom that has the same number of protons and electrons, but which has a different mass. Isotopes are created by **radioactive decay**, which is a process that causes changes inside of the nucleus of the atom. Due to this, isotopes of elements are often radioactive, and will break down and change over time. Isotopes are often named by giving the element name, then the weight of the isotope.
Ex: carbon with an atomic mass of 13 AMU would be called “Carbon-13”

Chemical Bonding

Chemical bonding is a process where atoms become connected to each other, forming molecules. The reason atoms will form chemical bonds is due to their electrons, specifically the valence electrons.

Each atom has space for up to eight valence electrons in their **valence shell** (outermost orbit). The **octet rule** states that all atoms will want to have a complete valence shell. In order to have a full valence shell, atoms will either want to gain or lose electrons. Gaining electrons will allow the atom to fill its current shell, while losing electrons will allow the atom to remove its outer incomplete shell and expose its inner, completed shell.

Ionic Bonding

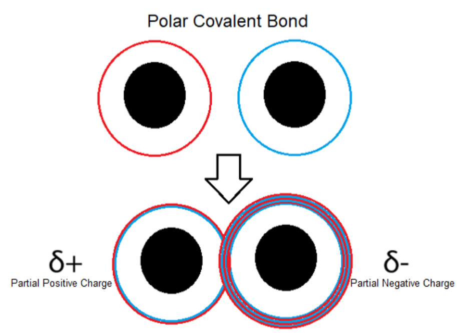
Ionic bonding occurs when one atom takes an electron from a neighboring atom. The first atom gains an electron becoming an anion,while the second atom loses an electron and becomes a cation. At this point, having two atoms with different charges near each other will cause the ions to attract each other, creating a molecule.
Ionic bonds are relatively weak, and can be broken up by the presence of other charges reducing the attraction between the charges inside the molecule.

Covalent Bonding

Covalent bonding occurs when pairs of atoms will share electrons with one another. In this case, the electrons will pass around both atoms, counting toward the valence shell of both.
When atoms have an equal attraction toward electrons, the shared electrons spend equal amounts of time around each of the atoms. When one atom attracts the electrons more strongly than the other, the electrons will spend more time orbiting that aton compared to the second. There are two types of covalent bonding: **polar covalent bonding**, and **nonpolar covalent bonding**.

Polar covalent bonds occur in atoms that have different levels of attraction toward electrons (**electronegativity**), leading the electrons to spend more time around one atom than the other. This creates one atom with more negative charges, and one with more positive charges.

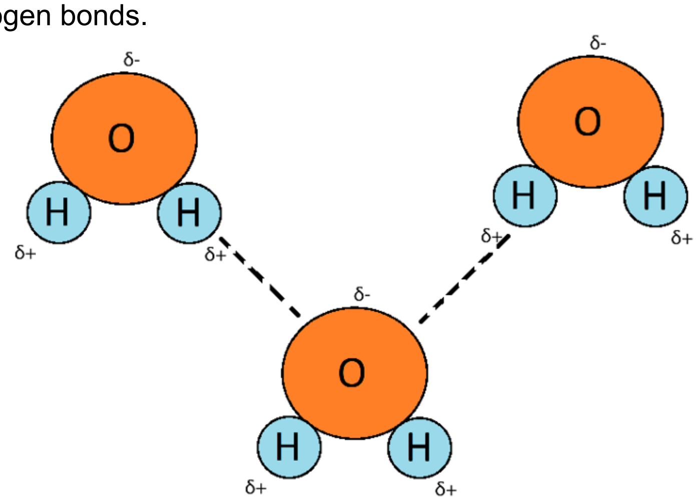
Nonpolar covalent bonds occur in atoms that have the same level of attraction toward electrons, leading to equal sharing of the electrons and their charges. In nonpolar molecules, there are no charges on the atoms.



Properties of Water

Water is a polar covalent molecule, made up of two hydrogen attached to a central oxygen atom, with the chemical formula H_2O. In water, the oxygen atom is slightly negatively charged, while the oxygen is slightly positively charged. This causes small attractions between the hydrogen and oxygen of adjacent water molecules, called **hydrogen bonds**.

These hydrogen bonds are responsible for many of the properties of water. Due to these bonds, molecules are held closer together, and are able to affect each other more than they would be able to without the hydrogen bonds.



The special properties usually associated with water are:

- Cohesion - The ability of water molecules to bond to other water molecules. The bonds between water molecules can be seen in surface tension
- Adhesion - The ability of water molecules to bond to non-water molecules. This creates capillary action, which allows water to stick to and climb surfaces
- Thermal Stability - It is hard to heat up or cool down water. The bonds between water molecules allow it to disperse heat easily, making it hard to change temperature.
- Solvency - Water can dissolve ionic bonds, and carry ions and other molecules in solution. The positive and negative charges in water attract ions, weakening and separating ionic bonds.
- Chemical Reactivity - Water speeds up the rate of chemical reactions by allowing chemicals to come into contact more easily when carried in water.

Energy and Work

Work is the ability to create a force, or create a movement. Energy is what fuels the ability to perform work. When energy is used to perform work, the energy is transformed into a different type of energy. According to the **law of conservation of energy**, energy cannot be created or destroyed, only changed from one form to another.

Types of energy

There are many types of energy that exist, based on the type of work that the energy is being used to complete.

- Electrical energy is used to move electrical charge through materials
- Kinetic energy is used to cause objects to move
- Chemical energy is used to bond atoms and molecules together
- Thermal energy controls the temperature of an object
- Electromagnetic energy creates waves of light, radio and other types of transmissions
- And several others…

Depending on the process that is occurring, one of more of these types of energy may be used, and changed into another type.
Ex: burning wood (chemical energy), will create thermal energy (heat)

Chemical Reactions

Chemical reactions are processes that change one type of substance into another. Some of the common types of chemical reactions are:

- Synthesis reactions, which combine two or more atoms together to create a more complex molecule
- Decomposition reactions, which break apart molecules to create simpler substances
- Exchange reactions, which will switch a piece of one molecule for a piece from another molecule

Catalysts and Enzymes

When performing chemical reactions, it is possible to speed up the reaction by the use of a material called a **catalyst**. Different types of catalysts are required for different chemical reactions, and these catalysts can be made of different types of materials.
In living organisms, chemical reactions must occur at a rapid pace to support life, requiring the use of catalysts. In the body, there is a type of catalyst made of proteins called **enzymes** that are used to speed up the chemical reactions that are required for life.
Due to their structure, enzymes have certain requirements in order to function properly

1. The enzyme must be kept within a certain temperature range
2. The enzyme must be kept within a certain pH range

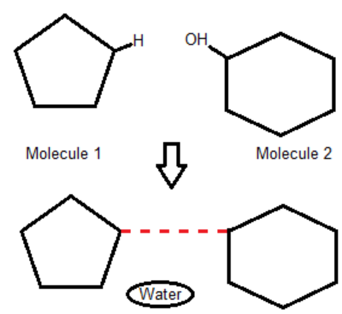
If an enzyme is exposed to temperatures or pH that is beyond what they are designed to work in, the protein will lose its shape (**denaturation**), preventing the chemical reactions that rely on them to function.

Organic Compounds

Organic compounds are chemical compounds mainly built from carbon and hydrogen. These chemicals are often found in living organisms, and are important to their function. Organic molecules are usually formed by taking simple molecules (**monomers**) and bonding them together in order to make more complex molecules (**polymers**)

Creating and Breaking down Polymers

The creation of polymers relies on a chemical reaction called **dehydration synthesis**, which removes a hydrogen atom from one molecule as well as a hydrogen and oxygen from a second molecule. These are combined to create a water molecule which is released, while the atoms that have lost covalent bonds on each molecule will create a new covalent bond that connects them together



To break down a polymer and release the monomers it is made of,
the opposite process occurs. First the bond between the molecules is broken down, while a water molecule is separated. A hydrogen is attached to one molecule, and the second hydrogen and the oxygen is attached to the second molecule. This reaction is called **hydrolysis**.

Carbohydrates

Carbohydrates are commonly referred to as sugars. They are composed of carbon, hydrogen, and oxygen in various combinations. In general, all sugars will have a ratio of one carbon, to two hydrogens, and one oxygen molecule.
Ex: the carbohydrate monomer glucose has the chemical formula $C_6H_{12}O_6$

Carbohydrate Monomers

The simplest carbohydrates are generally categorized as pentose (having 5 carbons), or hexose (having 6 carbons).
The pentose monomers are **ribose** and **deoxyribose**, and are used in the production of nucleic acids.
The hexose monomers are **glucose**, **fructose**, and **galactose**, which are used as sources of energy by the body.

Carbohydrate Polymers

When performing dehydration synthesis to create carbohydrates, the covalent bond between the monomers is called a **glycosidic bond**. Carbohydrate polymers are named using a prefix that represents the number of monomers that make up the polymer, and the suffix -saccharide. Two monomers use the prefix di-, three use the prefix tri-, larger numbers of monomers are usually represented by the prefix poly-.
Ex: a carbohydrate made of three glucose molecules would be called a trisaccharide.

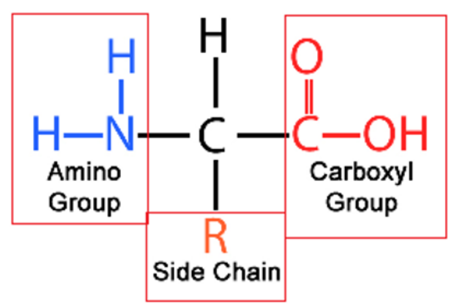
Some polymers of carbohydrates have specific names. Glycogen is a polysaccharide used to store energy in animals. Starch is a polysaccharide used to store energy in plants. Cellulose is a polysaccharide used to give strength and build structures in plants.

Proteins

Proteins are some of the most important chemicals used in the body. Among many uses, they are used to create structures in the cells that allow the cells to perform many of their functions.

Amino Acids

The monomer of protein is the amino acid. Amino acids can be broken down into several sections. The **amino group** is made of a nitrogen and two hydrogen. This is connected to a central carbon atom. On the opposite side is the **carboxyl group** made of one carbon, two oxygens, and a hydrogen. Below the central hydrogen is the **side chain**, which will have different chemical structures based on the type of amino acid.



Protein Polymers

When performing dehydration synthesis to create proteins, the covalent bond between the monomers is called a **peptide bond**. Protein polymers are named using a prefix that represents the number of monomers that make up the polymer, and the suffix -peptide. The prefixes used are the same as in carbohydrates.

Protein Structures

When proteins form, the side chains of different amino acids will attract or repel one another, causing the protein to bend and twist into different shapes. Protein structures are labeled based on the complexity of the structures formed.

- **Primary structures** consist of a chain of amino acids
- **Secondary structures** consist of a protein that is entirely arranged into a spiral (**alpha helix**), or a folded flat structure (**beta sheet**)
- **Tertiary structures** have multiple substructures in a single protein
- **Quaternary structures** are created by bonding together multiple proteins to form a single, more complex protein

The functions of proteins are directly tied to their shapes. Enzymes mentioned earlier, speed up certain chemical reactions due to having unique shapes that exactly match the chemicals they interact with. If a protein's shape is altered, it will lose its ability to function.

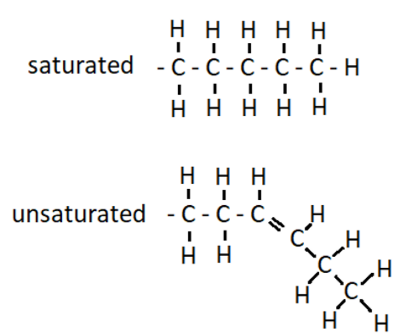
Lipids

Unlike carbohydrates and proteins, lipids are unable to mix with water, a chemical property called being **hydrophobic**. There are multiple types of lipids, only some of which form polymers.

- **Fatty acids** are chains of carbon and hydrogen, and are one of the components of triglycerides.
- **Triglycerides** are composed of a single **glycerol** molecule that has had three fatty acids attached to it by dehydration synthesis. It is broken down for energy in the body.
- **Phospholipids** are a glycerol molecule that has two fatty acids attached to one side and one **phosphate** group attached to the other. Phosphate is **hydrophilic**, which means it can bond to water. Phospholipids are used in the production of cell membranes
- **Eicosanoids** are chains of carbon and hydrogen that are used as chemical signals in the body.
- **Steroids** are sometimes referred to as **cholesterols**, and are used by the body primarily to produce hormones.

Saturated and Unsaturated Fats

The chains of carbon and hydrogen that make up fatty acids can be described as saturated or unsaturated based on their appearance and structure.



Saturated fats have a chain of carbons connected to each other by a single covalent bond, while having two hydrogens covalently bound to them on either side.

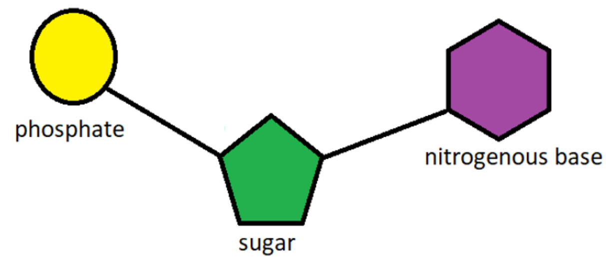
Unsaturated fats have some carbons that have formed two covalent bonds with each other. These carbons are only able to form a single hydrogen bond, leaving a space on one side of the chain without any hydrogen, causing the chain to curve.

Saturated fats take up less space, and will be solid at room temperatures. Unsaturated fats spread out and take up more space, and will be liquid at room temperature.

Nucleic Acids

Nucleic acids are special compounds used by the cell to store information for how to assemble proteins. The monomer form of the nucleic acids is the **nucleotide**, while the polymer forms are **ribonucleic acid** (**RNA**) and **deoxyribonucleic acid** (**DNA**)

Nucleotide Structure



Nucleotides are composed of a phosphate, a sugar, and a nitrogenous base.
The phosphate is responsible for forming bonds between different nucleotides in a polymer.
The sugar will alter the shape of the molecule. The sugar ribose is used to create a nucleotide for an RNA molecule, while deoxyribose is used to create nucleotides for DNA molecules.
The nitrogenous bases are used to encode the information stored in the polymer. There are a total of five nitrogenous bases, three are used in both DNA and RNA, while one is only used in DNA, and the last is only used in RNA.

- **Adenine** (**A**), **Cytosine** (**C**), **Guanine** (**G**) are found in both molecules
- **Thymine** (**T**) is only found in DNA
- **Uracil** (**U**) replaces thymine in RNA

The different nitrogenous bases are complementary, and will bond in pairs. Adenine will bond to thymine in DNA, or uracil in RNA. Cytosine will bond to Guanine.

Compounds and Mixtures

When chemicals form a bond after having a chemical reaction, they will form a compound. Compared to the original chemicals, compounds will have different chemical properties. Additionally, the chemicals in a compound cannot be separated from one another without another chemical reaction.
In comparison, a mixture is created by placing different chemicals in the same location without performing a chemical reaction. The chemicals retain their original properties, and are able to be separated from one another.

Mixtures of Solids and Liquids

When mixing solids and liquids, the liquid is referred to as the solvent, while the solid is referred to as the solute. Depending on the appearance of the mixture, we can describe it as a **solution**, **colloid**, or a **suspension**.
Solutions appear clear, with very small particles held by the fluid. The solid particles will not separate from the liquid over time.
Colloids will appear cloudy or colored, with small particles held by the fluid. The solid particles will not separate from the liquid over time.

Suspensions will appear cloudy or colored, with large particles that rely on the movement of the water to be kept mixed together. If allowed to sit, the solid particles will separate from the liquid.

pH

pH is a scale used to measure how acidic or basic a material is. In chemistry, the **hydrogen ion** (**H^+**) is associated with acidity, and the **hydroxide ion** (**OH^-**) which is associated with bases. On the pH scale, 7 represents neutral, with equal amounts of H^+ and OH^-. pH levels below 7 indicate acids, where there is more H^+. pH levels higher than 7 indicating bases, with higher amounts of OH^-

The pH scale is logarithmic, meaning that the numbers are actually powers of 10. This means that there is 10x more acid present in pH 4 than there is in pH 5.

The pH of most body fluids is between 7.35-7.45

Cellular Level of Organization

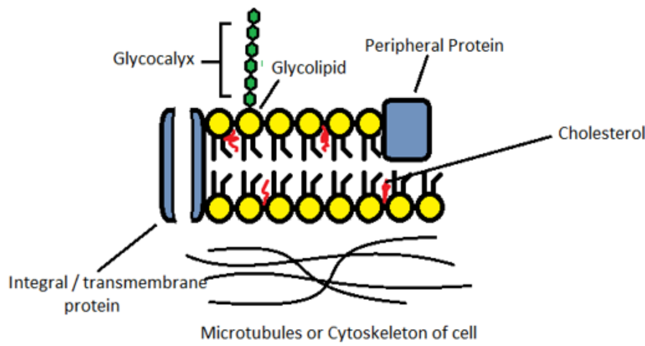
The cells are the smallest living components of the body systems. Each cell is capable of performing the activities described in the characteristics of life. These functions are performed using smaller internal structures called the organelles that each perform simpler functions.

Organelles

The organelles are the major structures inside of the cell.

Cell membrane

The cell membrane is primarily composed of a **phospholipid bilayer**, two layers of phospholipids with the fatty acid chains pointed inward, with the phosphate heads facing outward. This creates a barrier that prevents the movement of water and hydrophilic molecules, preventing transportation between the inside and outside of the cell.



Attached to these phospholipids are membrane proteins, some of which pass entirely through the membrane (**transmembrane proteins**), while others are attached only to the inner or outer layer of the membrane (**peripheral proteins**). These proteins perform several functions, allowing for transport of materials across the membrane (gates and channels), allow hormones to bond to the cell (receptors), serve as enzymes, identify the cell, and connect the cell to surrounding cells.

Below the membrane are the microtubules which make up the **cytoskeleton** of the cell, providing support and defining the shape of the cell.

The **glycocalyx** are carbohydrate chains on the surface of some cells. This serves as an outer barrier, preventing certain materials from being able to contact the cell.

Cellular Transport

In order to move materials from one side of the cell membrane to the other, there are three types of transport.

Active Transport

Active transport uses energy to activate proteins on the surface of the cell that act as pumps, moving materials from one side of the membrane to the other. Due to the use of energy, the material can be moved regardless of how much is already on either side of the membrane.

These proteins can move multiple chemicals at the same time. If these chemicals are all moved in the same direction, we call this protein a **symport**. If some chemicals are moved into the cell, while others are moved out of the cell, we call this protein an **antiport**.

Passive Transport

There are several types of passive transport, but all share the common point of not requiring energy to be spent to move materials.

Diffusion moves materials from areas of higher concentration towards areas where there is lower concentration. This is taking advantage of the tendency of materials to spread out to force material from one side of the membrane to the other. When diffusion uses a protein channel to move materials, there is less resistance, causing the transport to occur more quickly. This is called **facilitated diffusion**. **Simple diffusion** transports materials through the membrane without use of a protein.

Osmosis is the movement of water from areas of high concentration to lower, *across a semipermeable/selectively permeable membrane*. Osmosis operates similarly to diffusion, but requires a membrane that blocks the transport of materials other than water. When comparing the concentration of liquids, we use the following terminology

- **Hypotonic** solutions contain fewer solids and more water than the other solution.
  This will cause water to leave a hypotonic solution and enter the other solution
- **Isotonic** solutions contain the same amount of water and solids as the other solution.
  Water will not enter or leave if there is an isotonic solution
- **Hypertonic** solutions have more solids, and less water than the other solution.
  This will cause water to leave a hypertonic solution and enter the other solution

Vesicular Transport

This method is used to transport particles that are too large to fit into membrane proteins, or large quantities of materials at the same time.
When moving materials into the cell, a process called **endocytosis**, the cell membrane will fold inward, forming a pocket around the material that is being transported. This pocket will then seal shut and separate from the membrane, entering into the vell.
Moving materials out of the cell is called **exocytosis**, and requires a vesicle produced by the golgi apparatus to bond to the cell membrane, opening a hole in the membrane and allowing the contents of the vesicle to leave the cell.

Nucleus

The nucleus is an inner membrane inside the cell that surrounds the cell's genetic material. The nucleus will prevent the DNA inside from exiting, while blocking many chemicals that can potentially damage the DNA from entering.

Nucleolus

The nucleolus is a structure inside of the nucleus that produces ribosomal RNA, which is used to assemble the ribosomes outside of the nucleus.

Endoplasmic Reticulum

The endoplasmic reticulum surrounds the nucleus of the cell. It is usually divided into two portions. The **smooth endoplasmic reticulum**, which specializes in breaking down and synthesizing lipids, and is capable of destroying toxic materials in the cell. The **rough endoplasmic reticulum** is involved in the transport and creation of proteins.

Ribosomes

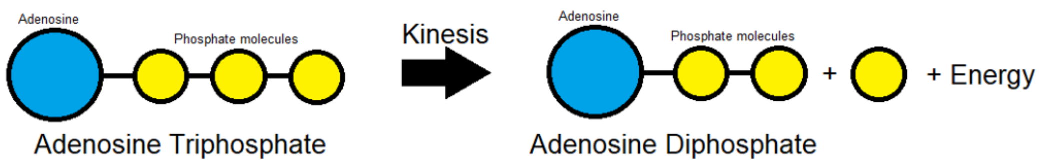
The ribosomes are the location where protein synthesis occurs. The ribosomes will receive amino acids and connect them together, forming protein chains. Most of the ribosomes are found on the rough endoplasmic reticulum.

Mitochondria

The mitochondria are sometimes called the power plant of the cell. A series of chemical reactions called **cellular respiration** will combine sugars and oxygen in order to produce energy, water, and carbon dioxide. This energy will then be used to create **adenosine triphosphate** (**ATP**), which stores chemical energy for later use in the cell.

ATP

In order to obtain energy from ATP, the structures in the cell must break one of the bonds connecting a phosphate molecule to the ATP in a process called **kinesis**. When this happens, the chemical bond energy that previously held the molecule together is released and able to be used by the cell for other purposes. This reaction results in the production of **adenosine diphosphate** (**ADP**) and a phosphate molecule.



Golgi Apparatus

The golgi apparatus is sometimes called the post office of the cell. It is responsible for wrapping up materials either for storage inside the cell, or for transport through the membrane by exocytosis.

Centrioles

Centrioles are bundles of protein tubules that play an important role in the division of the cell.

Peroxisomes

Peroxisomes are sacs containing protective enzymes. These enzymes are used to break down certain harmful substances inside the cell, such as hydrogen peroxide, protecting the cell.

Lysosomes

Lysosomes are sacs containing digestive enzymes. These enzymes are used to break down damaged organelles in order to create space for the assembly of a replacement. In immune cells, the lysosomes are also used to destroy foreign cells that have been brought into the cell by endocytosis.

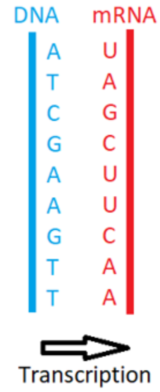
Vacuoles

Vacuoles are used to store materials inside of the cell. They are produced by the golgi apparatus.

Protein Synthesis

In order to make a protein that will be capable of performing a certain function, the amino acids in that protein must be assembled in the correct order. The human body assembles proteins using 20 different amino acids, and each protein can have from ten to tens of thousands of amino acids. Due to this complexity, each protein our body can make is assembled using a recipe that is stored in the DNA.

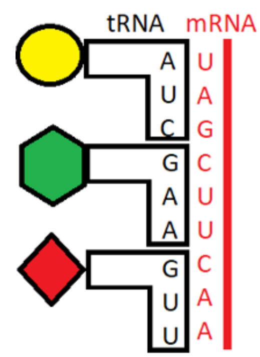
Transcription



While the DNA is inside of the nucleus, the site of protein synthesis is the ribosomes, located outside the nucleus. Since DNA cannot leave the nucleus, a copy is made of the portion containing the recipe for a single protein, using a molecule called **messenger RNA** (**mRNA**).

In order to produce mRNA, the DNA strand will separate, exposing the nucleotide chain. RNA nucleotides will then attach to the DNA, forming a copy. The newly created strand of mRNA will then detach from the DNA and be carried out of the nucleus. This will allow the DNA strand to close up.

Translation



After the mRNA strand enters the rough endoplasmic reticulum, it will be transported toward the ribosomes.

Along the way, the mRNA strand will run into pieces of **tRNA**. tRNA consists of three nucleotides on one side, and an amino acid on the other. The tRNA is capable of bonding to mRNA that has complementary nucleotides. This process allows pieces of amino acids to be attached to the mRNA strand in a specific order, which corresponds to the recipe for the creation of that protein.

At the ribosomes, the strand of mRNA and tRNA will enter the ribosome. The ribosome will remove the amino acids from the tRNA before attaching it to the amino acid from the next piece of tRNA in the sequence. This will continue until all of the amino acids have been bonded together to create the protein.

Cell Cycle

The cell cycle describes all of the events in a cell's lifespan, from its creation, until it divides to form new cells. This can be divided into **interphase** and the **mitotic phase**.

Interphase

This describes the events inside of the cell while the cell is not in the process of dividing. Interphase begins when a new daughter cell has been created from the division of a previous cell, and will end when the cell begins its own division process.

- **G_0 -** this is the first and longest stage of interphase. The newly created cell will grow to full size, then begin performing the normal functions
- **G_1 -** Some professors include the events of G_0 in this step. In G_1 the cell is beginning its preparations for division. Copies of the organelles are produced to ensure there are enough for the two daughter cells
- **S** - DNA synthesis phase. During this stage, a copy of the DNA is created.
- **G_2 -** During this stage, the copied DNA is checked for errors, and any additional organelle or protein production that is required occurs.

Mitotic Phase

During this cell, cell division will occur. This phase has two stages, **mitosis** which is the division of the nucleus, and **cytokinesis**, the division of the cytoplasm.

Stages of Mitosis

1. **Prophase**
    - Membrane around the nucleus will break down
    - DNA will bunch together to form the chromosomes
    - Centrioles will separate and move to opposite sides of nucleus
2. **Metaphase**
    - Chromosomes will line up in the middle of the cell
    - **Spindle fibers** will extend from the centrioles to the chromosomes

3. **Anaphase**
    - The chromosomes separate, with a full set of chromosomes going to each side of the cell
4. **Telophase**
    - A new nucleus begins to form on each side of the cell
    - The **cleavage furrow** begins to form in the middle of the cell, pinching the membrane inward as cytokinesis begins.

Cytokinesis

During cytokinesis, tubules beneath the cell membrane will contract, pulling the cell membrane in the middle of the cell inward. This will eventually separate the cell into two compartments, which will then separate, forming two daughter cells.

Tissue Level of Organization

As described in the hierarchy of complexity, a tissue is a group of similar cells that work together to perform a role. In the human body, there are four primary tissue types: **epithelial**, **connective**, **muscular**, and **nervous**. These tissues will have different structures due to the different functions they perform

Epithelial Tissue

Epithelial tissues form borders between voids (empty spaces) and other tissue types. They regulate the movement of materials between different areas of the body.

Properties of Epithelial Tissues

Epithelial tissues have several properties associated with performing their job

- Highly mitotic - these cells rapidly reproduce as they are easily damaged due to their placement in the body
- Polarity - these cells have a distinct top (**apical**) and bottom (**basal**) surface
- Avascularity - these cells do not have a blood supply, instead they are supplied oxygen and nutrients from surrounding tissues by diffusion
- Cell junctions - all epithelial cells are connected to their neighboring cells by cell junctions
    - Tight junctions - these junctions draw the membranes of the two cells close together, preventing water and other materials from passing in between them
    - Gap junctions - these junctions create a pipeline that connects the cytoplasm of the cells together, allowing chemicals to flow from one cell to another
    - Desmosomes - these junctions connect the cytoskeletons of neighboring cells together, creating a very strong connection that prevents the cells from being moved
- Basement membrane - all epithelial tissues are surrounded by a thin layer of connective tissue that is responsible for supporting the epithelial tissue

When describing epithelial tissues, we describe the number of layers of cells, as well as the shape of the cells that make up the tissue. A single layer of cells is described as a **simple** tissue, while multiple layers are called a **stratified** tissue
There are three main cell shapes found in epithelial tissues. **Squamous** cells are flattened cells that are wider than they are tall and usually have an oval nucleus. Cuboidal cells are about as wide as they are tall, with a circular nucleus. Columnar cells are tall and wide cells, with an oval nucleus.

Simple Tissues

Simple Squamous

This tissue type is a single layer of squamous cells on top of a thin layer of connective tissue. To identify simple squamous tissue, look at the border of the void and the other tissues. Look for a very thin layer that appears slightly different than the tissue directly under it, with scattered oval nuclei.
Due to how thin this tissue is, it easily allows materials to be transported through it. It is commonly found in the lungs and small blood vessel (capillaries)

Simple Cuboidal

To identify simple cuboidal tissue, look for a layer of cuboidal cells surrounding a void. There may be several sets of separate simple cuboidal tissues in close proximity to each other. Look for small bands of tissue separating the cells of each set of cuboidal tissue.
Since cuboidal cells have more internal space, these cells are usually used for producing secretions. Groups of these cells are sometimes referred to as **glandular epithelium**. They are commonly found in the small glands of the body.

Simple Columnar

Simple columnar cells' apical surfaces are usually covered in **microvilli**, small protrusions that increase the surface area of the cell. When looking at these cells, you may see a fuzzy surface on the top surface due to the small size of the microvilli.
The microvilli of these cells provide a large amount of surface area, allowing these cells to have a large amount of transport proteins on their surface. These cells are usually involved in absorption of materials in locations such as the small intestines.

Pseudostratified Columnar

Pseudostratified columnar cells twist around each other, creating the illusion that there are multiple layers of cells. On the apical surface of these cells are **cilia**, small hairlike structures that are able to push materials across the surface of the cell. These cells often have mucus producing **goblet cells** embedded among them, producing a layer of mucus that covers the cells
These cells are normally found in the respiratory tract, where their mucus traps dust and germs, preventing them from entering the body. Their cilia will then transport the mucus to the mouth, where it is swallowed and destroyed by the digestive system

Stratified Tissues

Stratified Squamous

Stratified squamous tissues have multiple layers of squamous cells connected to each other by desmosomes and tight junctions. Due to the multiple layers of interconnected cells, this tissue is very difficult to pass through, and acts as a barrier between the inside and the outside of the body. It is found in the skin and mucous membranes.

Stratified Cuboidal

Stratified cuboidal cells are similar in function to simple cuboidal tissues, but are capable of producing larger quantities of secretions. These cells are usually found in the large glands of the body, such as the salivary, sweat, and mammary glands.

Stratified Columnar

Stratified columnar cells are rare in the body. These cells are capable of producing some secretions, and have a protective function due to their multiple layers. They can be found in the male urethra, anus and uterus.

Transitional Epithelium

Transitional epithelium is a unique type of epithelial tissue, where the cells that make up the tissue do not have a constant shape. These cells are capable of stretching and expanding. Images of transitional epithelium can be identified by noticing cells of different shapes in the same tissue.
These cells are found in the urinary bladder and ureters, where their ability to stretch increases these organs to stretch as they fill with urine.

Connective Tissue

Connective tissues are supporting tissues found throughout the body. They help provide structural support, strength, physical protection, and the ability to move in cooperation with muscular tissue.

Properties of Connective Tissue

Connective tissues are composed of cells that produce fibers and **ground substance**, a material that separates and supports the tissues and fibers of the tissue.

- **Collagen fibers** are long, thick, relatively straight fibers used to add strength
- **Elastic fibers** are long, thin, flexible, wavy fibers used to add flexibility and the ability to recover their original shape if the tissue is put under pressure.
- **Reticular fibers** are shorter, thin fibers that branch apart, creating networks of connected fibers. Used by cells of the immune system for transport and support.

Loose Connective Tissue

Loose connective tissues can be identified by the space in between the fibers and cells in the tissue.

Areolar Connective Tissue

Areolar connective tissue can be identified by widely spread out cells, collagen, and elastic fibers. This tissue forms the basement membranes underneath all epithelial tissues. It provides structural support and blood supply for epithelial tissues.

Reticular Connective Tissue

Reticular connective tissue consists of a network of reticular fibers connected to widely spread cells. Due to the shape of the fibers, slides will sometimes resemble branches of a tree covered by leaves. This tissue is found in organs of the immune system.

Adipose Connective Tissue

This tissue is composed of special cells called **adipocytes**, or **ring cells**. These cells store fat in very large vacuoles that take up the majority of the internal volume of the cell. Adipose connective tissue will sometimes look like a picture of soap bubbles.
Adipose connective tissue is found surrounding most organs, and beneath the skin. This tissue provides cushioning, insulation, and stores fat that will be used to produce energy.

Dense Connective Tissues

Dense connective tissues feature tightly spaced fibers and cells.

Dense Regular Connective Tissue

Dense regular connective tissue is composed of tightly packed layers of collagen fibers. These fibers are arranged so that all of the fibers travel in the same direction. This maximizes the amount of support that these fibers can provide along that direction.
This tissue is found in the **tendons** (connect bone to muscle), and **ligaments** (connect bone to bone)

Dense Irregular Connective Tissue

This tissue is also composed of tightly packed collagen fibers, however in this tissue the fibers are arranged randomly. This creates a tissue that will have some support no matter the direction it is twisted or pulled.
This tissue is primarily found in the dermis of the skin.

Dense Elastic Connective Tissue

This tissue is composed of tightly packed elastic fibers. This creates a tissue that is capable of resisting stretching and returning to its original size.
This tissue is found in the arteries and other large blood vessels.

Cartilage

Compared to the previous connective tissues, the ground substance in cartilage is much more dense, becoming stronger and reducing the speed that materials can diffuse through it. Due to this reduced diffusion, the cells in cartilage are surrounded by empty spaces called **lacunae**, which increase the surface area that these cells can absorb nutrients from.

Hyaline Cartilage

Hyaline cartilage has a ground substance that appears cloudy or chalky, making it difficult to see the fibers it contains. Hyaline cartilage has a large quantity of both collagen and elastic fibers, giving it both strength and the ability to flex slightly.
This tissue is used in places that require strength, but more flexibility than bone can allow, such as the connection between the ribs and the sternum. Hyaline cartilage is also found in the joints, where a thin layer of this cartilage acts as a non-stick surface to prevent friction where bones meet.

Elastic Cartilage

Elastic cartilage contains only elastic fibers, set in a dense ground substance. This creates a hard but very flexible material. Elastic cartilage is found in the outer ears, and the **epiglottis** of the throat.

Fibrocartilage

Fibrocartilage is made of layers of collagen fibers and cells. This structure allows fibrocartilage to act as a shock absorber, absorbing impacts in order to prevent damage to the other tissues of the body.
This tissue is found in the meniscus of the knees, the intervertebral discs, and connects the anterior portion of the pelvis as the pubic symphysis.

Bone

Bone is a special connective tissue whose ground substance is made of a solid substance, composed of a calcium compound. Bone tissue forms round structures called **osteons**, made of multiple layers of rings called **concentric lamellae**. Bones provide the body with its shape, protect organs, and act as levels for the muscles to move the body.

Blood

Blood is another special connective tissue with a liquid ground substance called **plasma**. Special fibers called fibrin are carried as part of the liquid plasma. Blood is used to transport oxygen, nutrients, wastes, and body heat throughout the body.

Muscular Tissue

Muscle tissue is specially designed to be able to contract in order to move the body, and materials within the body.

Skeletal Muscle

Skeletal muscles are long, straight, multinucleated cells covered in **striations** (alternating light and dark bands). These tissues operate under conscious control, and are responsible for voluntary movement of the body.
Skeletal muscle is found throughout the body, and is usually attached to the skeleton by tendons.

Cardiac Muscle

Cardiac muscles are visually similar to skeletal muscle due to their striations. Unlike skeletal muscle, the cells of cardiac muscle will branch and separate, and have a single nucleus. Cardiac muscle is involuntary and does not have any conscious control.
Cardiac muscle is found in the heart, and is responsible for the contraction of the heart which pumps blood.

Smooth Muscle

Smooth muscle is composed of short, diamond shaped cells. This tissue is often found surrounding organs and blood vessels. It is responsible for moving materials through the digestive system, and helps regulate blood pressure and blood flow. Smooth muscle is involuntary and does not have any conscious control.

Nerve Tissue

Nerve tissue is designed to send electrochemical signals throughout the body. This is the primary tissue found in the nervous system.
Nervous tissue is composed of **neurons** (nerve cells), and glial cells (supportive cells). Neurons have smaller projections extending around them called **dendrites** that collect signals and carry them to the cell, as well as a longer projection called the **axon** which carries signals outwards towards other cells.

The Integumentary System

The skin is the primary organ of the integumentary system, and the largest organ of the body. The integumentary system has several functions:

- Protection from injury and infection, by preventing harmful substances from penetrating into the body
- Control of loss of water from the body, by having multiple layers of cells forming water tight connections preventing water from easily escaping from the body.
- Vitamin D synthesis requires chemical reactions that occur in the skin.
- Temperature regulation due to secretion of sweat, and insulation from subcutaneous fat.
- Sensation of the environment through nerve receptors located in the skin.

Skin

The skin consists of two layers, the outer **epidermis** and inner **dermis**. Below these layers is a connective tissue layer called the **hypodermis**, which while it supports the skin, is not considered a part of the skin

Epidermis

The epidermis is the outer layer of the skin. It is primarily composed of stratified squamous epithelium, with other supporting cells. The squamous cells of the skin are called **keratinocytes**, due to their ability to produce the protein **keratin**. Keratin increases the toughness of the skin cells, and makes them more resistant to damage. The epidermis is divided into five layers.

Stratum Basale

Stratum Basale is the deepest layer of the epidermis. This layer is one cell thick, and contains three specialized cell types

- **Stem cells** - Stem cells are sometimes called undifferentiated cells. These are cells that can develop and become other, more specialized cells. These cells will produce the squamous cells that make up the majority of the epidermis.
- **Melanocytes** - these cells will produce **melanin**, the pigment that colors the skin. The more melanin that is released into the skin, the darker the skin color will be. Melanin serves to protect the skin and underlying tissues from ultraviolet (UV) radiation from the sun. Additional melanin will be released in response to damage from UV radiation, temporarily increasing protection against further damage.
- **Merkel** (**tactile**) cells - these cells are sensory receptors. These cells are responsible for providing the sense of touch.

Stratum Spinosum

Superficial to stratum basale is stratum spinosum. This layer is primarily composed of stratified keratinocytes. In this layer, the desmosomes that bind the cells together are visible. As the keratinocytes move toward the surface of the epidermis, the cells produce additional keratin and begin to flatten out further.
Dendritic (**langerhans**) cells can be found in this layer. These cells are macrophages, specialized immune cells that are able to move through the tissue of the epidermis searching for infection, toxins, and other disease causing organisms.

Stratum Granulosum

Stratum granulosum is superficial to stratum Spinosum. In this layer keratinocytes begin to die due to lack of oxygen and nutrients. By this point, the keratin in the cells has accumulated to the point where it forms **keratin granules**, which are visible inside of the cytoplasm.

Stratum Lucidum

Stratum lucidum is a special layer superficial to stratum granulosum in the thick skin of the palms of the hands and the soles of the feet. This extra layer provides additional protection for these two areas as they are exposed to the most pressure and damage. This layer appears as a mostly clear section of cells under microscopy.

Stratum Corneum

Stratum Corneum is the most superficial layer of the epidermis. The cells in this layer are directly exposed to the surrounding environment, causing the outer layers of cells to flake off and expose underlying layers.

Dermis

Located deep to the epidermis, the dermis is primarily composed of connective tissue. The dermis is separated into two layers, the **papillary layer** and the **reticular layer**.

Papillary Layer

This layer makes up the upper 15-20% of the thickness of the dermis. It is composed primarily of areolar connective tissue that carries blood vessels that support the epithelial tissues of the epidermis. This layer of the dermis is characterized by finger-like protrusions of the areolar tissue called the **dermal papillae**, matched by downward protrusions of epithelial tissue called **epidermal ridges**. These structures lock the dermis and epidermis together, and give rise to the fingerprints.

Reticular Layer

The reticular layer is primarily composed of dense irregular connective tissue. This layer is much thicker than the papillary layer and primarily acts to prevent ripping and tearing of the skin. The dermis is also the location of the **hair follicles**, **sweat glands**, nervous tissues, and numerous blood vessels.

Hair and Nails

Hair and nails are accessory organs of the skin. They are composed of dead keratinized cells.

Hair

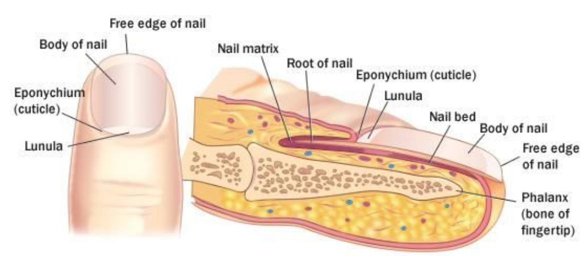
A single hair is referred to as a **pilus**, with the plural being **pilli**. Hairs are found throughout most of the skin. Fine, pale hairs called **vellus** account for two-thirds of the body hair in women, and one-tenth of the body hair in men. **Terminal hair** is longer, thicker, and more heavily pigmented than vellus. This hair makes up the hair on the head, eyebrows, eyelashes, facial hair in men, and axillary and pubic hair after puberty.

Hairs originate from the **hair bulb**, located within the dermis. The hair bulb grows around and contains the **dermal papilla** (not to be confused with the dermal papillae of the papillary layer), which provides blood supply and nutrition for the growing hair. Around the dermal papilla is a region called the hair matrix, the site of hair growth.

After exiting the bulb, the hair will continue up through the skin as the **hair root**, with the portion above the skin called the **hair shaft**.

Nails

Fingernails and toenails are composed of thin, flat layers of dead keratinized cells. The nails are supported by the underlying epithelium, which is called the **nail bed**. The nails originate from a region known as the **nail matrix**, forming a region under the surrounding epithelium called the **nail root**. From the nail root, the nail grows outward from under the **nail fold**, the epithelium covering the root. The end of the nail fold connects to the nail at the **eponychium**. The visible portion of the nail is called the **nail plate**, which includes the portion attached to the finger, the **nail body**, the portion overhanging the end of the finger, the **free edge**, as well as the eponychium.



Glands of the Skin

The skin is also the location of several **exocrine glands** that will release their contents to the surface of the skin through a duct. There are two different types of glands, **apocrine** and **merocrine** glands. Apocrine glands will accumulate secretions inside of the cells, and release those secretions by breaking down the cells. Merocrine glands will release their secretions by exocytosis, leaving the cells intact.

Sweat Glands

Sweat glands will produce secretions that are primarily composed of water and salt.

Merocrine Glands

These are the most common sweat glands, and are located throughout the body. These glands produce odorless sweat for the purpose of cooling the body (**thermal regulation**).

Apocrine Glands

These glands are located in the regions covered by facial, axillary, and pubic hair. The secretions from these glands cause them to function as scent glands. These glands will produce secretions in response to stress and sexual excitement.

Sebaceous Glands

These glands will produce oily secretions called **sebum**, which is used to prevent the skin and hair from becoming dry and brittle.

Ceruminous Glands

These glands are found in the external ear canal, and will produce **cerumen**, commonly called earwax. Cerumen helps waterproof the ear canal, blocks foreign particles from entering the ear, and destroys bacteria.

Mammary Glands

These glands are the milk producing glands located in the chest. These glands will develop in the female breast due to the hormones produced during pregnancy.

Bone tissue and Skeletal System

The skeletal system is composed of the bones, cartilages, and ligaments of the body. The skeletal system plays several important roles in the body.

- It is responsible for the shape and support of the body, forming the structures that hold the other organs and tissues in place.
- The bones provide protection for many of the organs of the body, preventing injury due to impacts and piecing.
- The bones of the body act as levers, allowing the muscle tissue to move the body.
- The bones store important electrolytes such as calcium and phosphate, and help regulate the levels of these electrolytes in the body.
- The bone tissue houses the bone marrow, which produces blood cells for the body.
- Bone tissue can help regulate pH by absorbing or releasing OH^- ions.

Classification of Bones

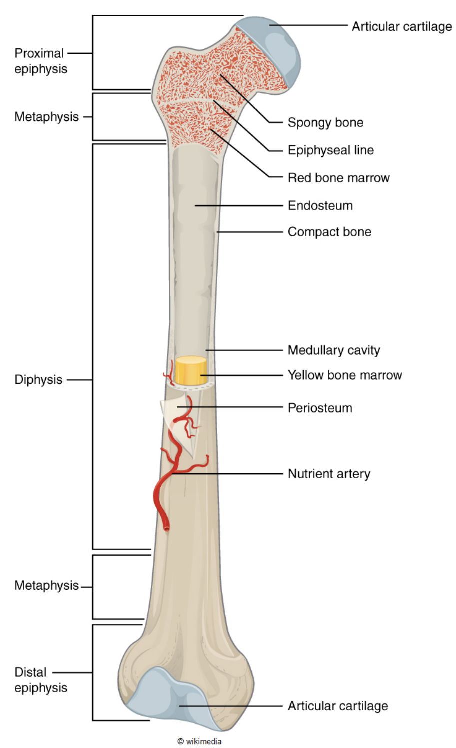
The bones of the body are categorized based on their shapes and functions

Long Bones

Long bones are longer than they are wide, allowing them to act as levers to produce movement.
The middle portion of a long bone is called the **diaphysis**, and is made of a layer of compact bone surrounding a hollow marrow cavity.
The ends of the long bones are called the **epiphysis**, and are made of a layer of compact bone surrounding spongy bone.This spongy bone is often the site of red bone marrow.

These two sections are separated by the **epiphyseal line** in adults, which is the remnant of the **growth plate**, the site of bone production in children and adolescents.

The outer surface of the bone is covered by a fibrous layer called the **periosteum**, which helps hold blood vessels in place on the surface of the bone.

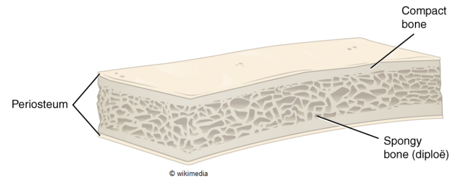


Short Bones

Short bones have similar length and width. They can be used to distribute force in certain joints, strengthening those joints and increasing their range of motion.

Flat Bones

Flat bones are plate-like bones formed of two layers of compact bone sandwiching a layer of spongy bone. These bones surround and protect the organs of the skull, thorax, and pelvis. Red bone marrow is commonly found in their spongy bone layer.



Irregular Bones

Irregular bones have complex shapes that do not fit the other categories. They can be found in the skull and vertebral column.

Histology of Bone Tissues

Bone tissues are a type of connective tissue, and as such are composed of cells, fibers, and the bony matrix

Bone Cells

There are four main types of cells found in bone tissue. These cells are responsible for the creation, destruction, and repair of the bony tissue.

Osteogenic Cells

Osteogenic cells are a type of stem cell found in the inner layer of the periosteum. These cells will develop to become **osteoblasts.**

Osteoblasts

Osteoblasts are the cells that produce the matrix that makes up the bones. These cells are unable to undergo mitosis, and can only be produced by the osteogenic cells. The matrix produced by these cells will accumulate minerals, hardening into the final bony matrix. These cells will become trapped within the bone, and transition to become **osteocytes**.

Osteocytes

Osteocytes can be described as the mature form of osteoblasts. These cells reside in lacunae in the bone tissue and have small tendrils that connect to neighboring cells through small channels called **canaliculi**. Osteocytes help maintain the bones by absorbing and secreting minerals into the bone matrix. They also detect when the bones are under strain, creating signals that trigger **bone remodeling**.

Osteoclasts

Osteoclasts are produced by the same stem cells that produce the blood cells. These cells are responsible for dissolving bone tissue and reclaiming electrolytes for the body.

Bone Matrix

The bone matrix is a mixture of collagen fibers, proteins, and **hydroxyapatite**, a mineral composed of calcium, phosphate, and hydroxide (OH^-) ions. When creating bone tissue, these electrolytes are removed from the blood to produce the matrix material.
Since hydroxide is associated with increased pH, removing it from the blood to create bone will cause the pH of the blood to decrease, becoming more acidic. When bone is broken down, these electrolytes are increased, and will cause blood pH to increase when hydroxide is returned to the blood.

Spongy Bone

Spongy bone is a lattice of small slivers of bone, rod shaped **spicules** and thicker plate shaped **trabeculae**. These pieces of bone are surrounded by bone marrow. While the strength of each small piece of bone is small, spongy bone allows forces to be distributed through the lattice, giving a good balance of strength and weight.

Compact Bone

In this bone tissue, layers of bony tissue form around hollow **central** (**haversian**) **canals**, forming rings of concentric lamellae. The structure created by the canals and the surrounding lamellae are called **osteons**. Osteons are connected to each other, creating a dense bony tissue. The central canals of adjacent osteons may be connected by **perforating** (**Volkmann**) **canals**. Blood vessels and nerves will run through the canals of compact bone.
Compact bone is extremely strong, but also extremely heavy. This causes the body to need to balance the need for strength compared to the need for additional muscle mass and energy cost for moving the additional weight.

Bone Development

The creation of bone is called **osteogenesis**, and will begin while a fetus is developing in the womb, continuing until early adulthood.

Intramembranous Ossification

Intramembranous ossification is a process that transforms **mesenchyme**, and early embryonic connective tissue into the flat bones of the skull and clavicles.

1. Layers of mesenchyme will condense, creating layers of connective tissue with large amounts of blood supply. Osteoblasts will be created by stem cells in the mesenchyme and begin creating small pieces of bony trabeculae.
2. Additional osteoblasts will gather on the trabeculae, and continue to create additional bony material, causing the trabeculae to expand and connect to neighboring trabeculae
3. Osteoblasts will continue to grow the bone outward, while osteoclasts will enlarge the spaces between the trabeculae, forming marrow cavities.
4. Trabeculae at the edges of the bone will grow together, forming a layer of compact bone. This creates a sandwich of spongy bone surrounded by two layers of compact bone.

Endochondral Ossification

Endochondral ossification is a process that transforms hyaline cartilage into bone tissue. In a fetus, hyaline cartilage creates forms that are used as models to create most of the bones of the body.

1. Hyaline cartilage forms in the shapes of the future bone. This cartilage is covered by a fibrous **perichondrium** that produces **chondrocytes**, the cells that create the hyaline cartilage.
2. The perichondrium ceases producing chondrocytes, and instead begins to produce osteoblasts. These osteoblasts will start to turn the outer surface of the cartilage into bone, starting from the midpoint and moving toward the edges.
   As this happens, fewer nutrients can enter the cartilage, causing the cells in the center of the cartilage to begin to expand and break down, forming the **primary ossification site**. As these cells die, minerals are released in the ossification site, causing a bony matrix to form
3. Blood vessels enter through the bony collar, in a process called **vascular invasion**. The blood will carry osteoblasts and osteoclasts to the primary ossification site. The osteoblasts will turn the surrounding tissue to bone, following which the osteoclasts will destroy the bone, leaving a hollow **primary marrow cavity**.
   This wave of ossification will progress along the epiphysis toward the diaphysis.
4. In the diaphysis, **secondary ossification sites** will form, starting the creation of spongy bone in the diaphysis that will progress toward the epiphysis.
5. A thin layer of cartilage will exist between the epiphysis and diaphysis called the **epiphyseal** (**growth**) **plate**. This cartilage will grow outward, before becoming ossified, allowing the bone to lengthen.
6. At adulthood, the epiphyseal plate will ossify, ending bone growth.

Bone Homeostasis

Over their lifespan, bones will become brittle due to accumulated damage, and be replaced with newer, stronger bone tissue to maintain the function of the skeletal system.

Bone Remodeling

Bone remodeling refers to the changes that occur in the bone due to stresses that they are placed under. **Wolff's law of bone remodeling** states that when bones are strained, they will grow thicker in order to better withstand the stress. Similarly, if bones are not stressed, the body will reduce the bone mass in order to reduce the weight of the body, reducing the amount of energy needed to move the body.

Changes in the thickness of bone are called **appositional growth**, and will occur due to the deposition of new bone material on the surface of existing bones. Changes in the length of the bones is called **interstitial growth**, and occurs due to the growth of the cartilage in the epiphyseal plates.

In addition to changes in the size of the bone due to stress or growth, the bone tissue is constantly undergoing a process of replacement, with older bone tissue being replaced by new bone.This allows the bones to replace sections that have been damaged or weakened. Approximately 10% of the bone tissue in the body is replaced each year.

Calcium Homeostasis

The bones are the main site of calcium storage in the body. Calcium is an electrolyte important for the function of the muscle and nerve tissues. Excess or deficient levels of calcium in the blood will cause these tissues to be unable to function normally. In order to manage blood calcium levels, calcium will be added to or removed from the bones. This process is managed by several hormones.

Calcitriol

Calcitriol is a form of vitamin D, produced by a series of chemical reactions in the skin, liver, and kidneys. Calcitriol will cause blood calcium levels to increase by several mechanisms

1. Calcitriol increases the absorption of calcium from food in the digestive system
2. Calcitriol stimulates osteoclasts, causing them to dissolve bone and release calcium and return it to the blood.
3. Calcitriol acts on the kidney, reducing the amount of calcium that is excreted in urine, instead returning it to the blood

All of these actions serve to increase the amount of calcium entering the body, while reducing the amount that is lost, causing calcium levels in the body to increase.

Calcitonin

Calcitonin is a hormone released by the **thyroid gland**. It has the strongest effect during childhood, having a small impact in adults. Calcitonin acts to decrease blood calcium, and will be released if blood calcium is too high

1. Calcitonin will stimulate osteoblasts, causing calcium to leave the blood and enter the blood.
2. Calcitonin will inhibit (block) osteoclasts, preventing breakdown of bone, preventing blood calcium from increasing.

These actions will cause excess calcium to be removed from the blood, while preventing blood calcium levels from increasing further.

Parathyroid Hormone (PTH)

Parathyroid hormone is a hormone released by the **parathyroid gland**. PTH acts to increase blood calcium, and is released if blood calcium is too low.

1. PTH stimulates osteoclasts, causing them to dissolve bone and release calcium and return it to the blood.
2. PTH acts on the kidney, reducing the amount of calcium that is excreted in urine, instead returning it to the blood
3. PTH increases the production of calcitriol in the kidney. Increased calcitriol levels will increase blood calcium levels.
4. PTH inhibits osteoblasts, preventing the creation of new bone tissue, and preventing calcium from being removed from the blood.

Joints

Any point where two bones meet is called a joint, or **articulation**. This applies regardless of if the bones are movable or not. Joints can be described by either the material they are created from, or from their ability to move.

Fibrous Joints

Fibrous joints are designed to hold bones tightly together, and are not designed to allow for movement. As such, they can be described as **synarthrosis**, or immobile joints. There are three types of fibrous joints. These joints use large numbers of fibers to hold two bones together.

Suture

Sutures hold the bones of the skull in place. They include **serrate sutures**, which form fibers between wavy interlocking protrusions between the bones of the skull. **Lap sutures** hold together the bones that overlap, connecting the top surface of one bone to the bottom surface of another. **Plane sutures** connect bones that have straight, non-overlapping edges.

Gomphosis

Gomphosis hold the teeth into the sockets in the upper and lower jaws.

Syndesmosis

Syndesmosis are long collagen fibers that act to prevent the bones of the lower arms and lower legs from being pushed away from each other.

Cartilaginous Joints

Cartilaginous joints connect two bones together through a bridge formed of cartilage. These joints are more flexible, and allow some movement. They are also called **amphiarthrosis** due to the degree of movement they allow.

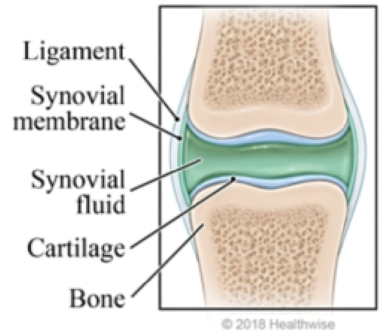
Synchondrosis

A **synchondrosis** is a joint formed of hyaline cartilage. The epiphyseal plate in the bones of children, or the connection between the first rib and the sternum are examples of synchondrosis.

Symphysis

A **symphysis** is a joint formed of fibrocartilage. These can be found connecting the vertebrae together as the intervertebral discs, as well as connecting the bones of the anterior pelvis at the pubic symphysis.

Synovial Joints



Synovial joints are formed by ligaments surrounding the connection between two bones, forming a hollow **synovial cavity**. On the inner surface of the ligaments there is a layer of epithelial tissue called the **synovial membrane** that secretes lubricating **synovial fluid**. On the surface of the bones there is a layer of hyaline cartilage, called the **articular cartilage**, that acts to reduce friction and reduce damage to the bone due to movement.

Synovial joints allow for large ranges of motion between the bones. Due to the amount of motion they allow, they are also called **diarthrosis**, or mobile joints.

Synovial joints are often described by their axes of motion. This refers to how many different directions they can move in, in relation to the sagittal, frontal, and transverse axes. Monoaxial joints can move in one plane, biaxial joints can move in two planes, while multiaxial joints can move in all three planes.

Ball and Socket

Ball and socket joints are formed by the joint between a rounded protrusion of one bone, and a cup shaped socket of another. These joints are multiaxial, and make up the shoulder and hip joints.

Hinge

Hinge joints are formed by the joint between a convex (outward curving) protrusion of one bone connecting to a concave (inward curving) groove in another. These joints are monoaxial, and can be found in the elbow, and between the phalanges of the hands and feet.

Pivot

Pivot joints are structurally similar to hinge joints, with a convex protrusion of one bone fitting into the concave groove of another bone. However in pivot joints, this joint is aligned along the length of the bone, rather than across the narrow edge. These are monoaxial joints, with the two bones to be able to rotate around the joint. These joints can be found between the radius and ulna, as well as between the atlas (C1) and axis (C2) in the vertebral column.

Plane

Plane joints are formed between flat surfaces of adjacent bones, allowing the bones to slide against one another. These joints are slightly biaxial, having a limited range of motion due to the length of the connected bone surfaces. They form the joints between the carpals, tarsals, and the articular processes of the vertebrae.

Saddle

Saddle joints are formed between concave surfaces of two bones. This allows the bones to slide along the length of the curved portions of each bone, allowing for biaxial motion, with a limited range of motion.

Condylar

Condylar joints are formed between oval convex surfaces of one bone and a similarly shaped concave surface on the other. These joints are biaxial. Their shape allows for a small amount of motion when sliding side to side, and a larger degree of motion when bending.

Types of Motion in Articulations

Flexion - movement that reduces angle of the bones at the joint
Extension - movement that increases the angle of the bones at the joint
Hyperextension - an extension beyond the normal resting point of the joint
Protraction - movement that pushes joint anteriorly
Retraction - moves the joint posteriorly
Elevation - moves the joint superiorly
Depression - moves the join inferiorly
Circumduction - circular movement of the arm or leg
Rotation - one bone rotates around a second bone
Pronation - movement of the forearm that ends with the palm facing down
Supination - movement of the forearm that ends with the palm facing up
Inversion - movement of the feet that causes the soles to face inward
Eversion - movement of the feet that causes the soles to face outward
Dorsiflexion - movement of the ankle that shifts the foot downward (toe point in ballet)
Plantar Flexion - movement of the ankle that shifts the foot upward
Abduction - movement of the arms or legs away from midline of body
Adduction - movement of the arms or legs toward midline of body
Opposition - movement of the thumb to touch the fingers

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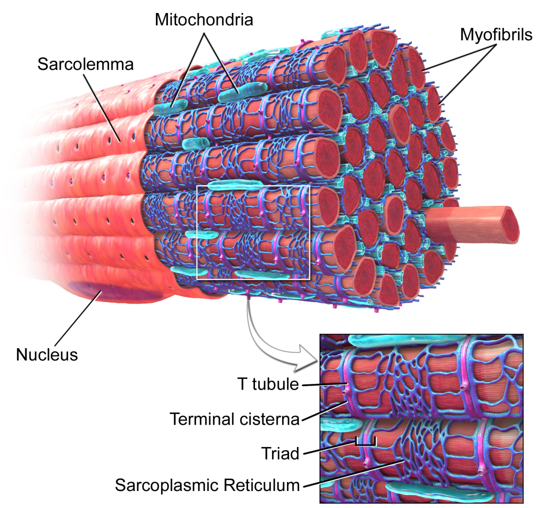
The Muscular System

The muscular system consists of the skeletal muscles throughout the body that can act under conscious control. The muscular system is responsible for several major functions:

- Movement, by pulling on the bones of the skeleton, the muscles can produce motion.
- Stability, by contracting and relaxing muscles, our bodies are able to maintain balance and control body posture.
- Controlling access to body openings by opening or sealing orifices
- Body temperature, due to the large amount of energy used by muscle tissue, some of this energy is transformed into heat, and is responsible for 85% of the body's heat production.

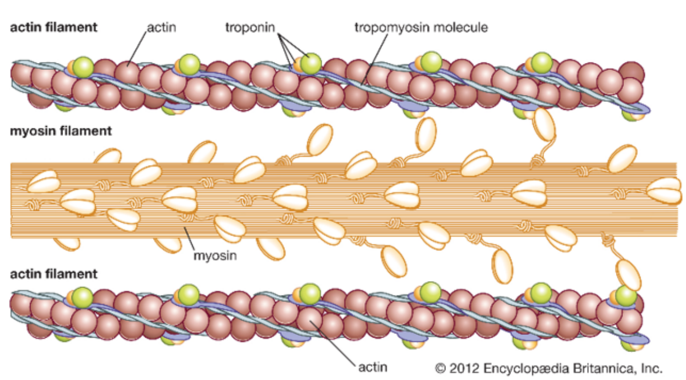
Muscle Cell



The muscle cell, or **muscle fiber** contains densely packed bundles of fibers, called **myofibrils**, numerous mitochondria, and multiple nuclei, surrounded by a membrane called the **sarcolemma**.

Each myofibril is composed of smaller fibers, called **myofilaments**, surrounded by a network of tubules called the **sarcoplasmic reticulum**. The sarcoplasmic reticulum is separated into segments by the **transverse tubules**, which form rings around all of the myofibrils at regular intervals. On either side of the transverse tubules, the sarcoplasmic reticulum terminates at the **terminal cisterna**. The structure formed by the joining of the terminal cisternae and transverse tubules are called **triads**.

Myofilaments



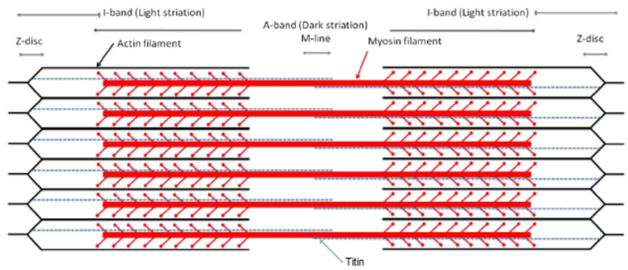
There are two types of filaments found inside of the myofibrils. There are **thick fibers** formed of a protein called **myosin**, covered in structures called myosin heads.

The other are **thin fibers**, primarily made of a protein called **actin**, which have a thread-like structure called **tropomyosin** attached to their surface by **troponin** molecules.

Sarcomere

The sarcomere is a structure found within the myofibrils, and is the site of muscle contraction. Each myofibril will have a large number of sarcomeres running down its length. These sarcomeres are what cause the striations of skeletal muscle.

Each sarcomere starts and ends at a **Z-disc**, which directly connects to the thin filaments. The Z-discs are also attached to a protein filament called titin, which will connect to the thick filaments and suspend them in the middle of the two Z-discs. The thick filaments are also connected to each other in the center of the sarcomere, at the **M-line**



Areas in the sarcomere where there are only thin filaments are called the **I-band**, and form the light colored striation on the muscle fiber. Areas in the sarcomere where there are thick filaments form the **A-band**, and form the dark colored striations on the muscle fiber. The area in the center of the sarcomere where the thin filaments do not normally reach is called the **H-band**.

The **sliding filament theory** explains the process by which the sarcomeres will cause a contraction. It states that the thick filaments will extend myosin heads to the thin filaments, form a connection, and then drag them inwards toward the M-line. Since the Z-discs are directly connected to the thin filaments this will pull the two Z-discs toward each other, causing the sarcomere to contract.

Electrically Excitable Cells

Muscle cells, as well as nerve cells, fall into a category called electrically excitable cells. These cells are able to change their voltages in response to outside signals, and then use this change in voltage as a signal to perform tasks within the cell. Voltage is a measurement of the difference in charges between two locations. In muscle cells, this change in voltage will be what causes the muscle contraction.

Sodium/Potassium Pump

The **sodium/potassium (Na/K) pump** is a special membrane transport protein responsible for moving sodium and potassium ions. This pump will simultaneously move three sodium ions out of the cell, while moving two potassium ions into the cell, functioning as an antiport. Sodium and potassium ions both have a charge of +1, which means that when these ions are moved the cell will gain two charges and lose three, for a net loss of one charge.

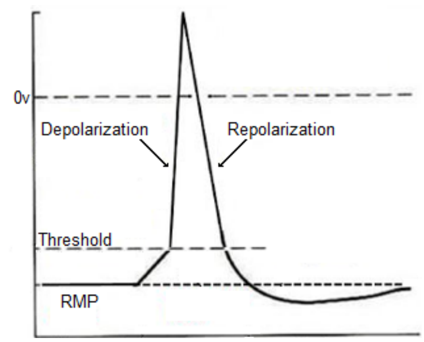
As the Na/K pumps work, voltage in the cell will decrease, while sodium concentrations decrease, and potassium levels increase. Outside the cell, voltage will increase, while sodium levels increase and potassium levels decrease. This causes a difference in voltage, as well as sodium and potassium concentrations between the inside and outside of the cell.

Resting Membrane Potential

As the Na/K pumps change the concentrations of sodium and potassium, diffusion will begin to move these electrolytes from the higher to the lower concentrations, causing sodium to enter the cell and potassium to exit the cell through simple diffusion. As the concentration differences are increased by the pumps, the rate of diffusion will also increase, until it reaches a point where the speed that the pumps move sodium and potassium will be balanced by the speed where diffusion moves them back. At this point, the number of charges in the cell stops decreasing, and the voltage becomes constant.
This steady voltage due to the balance of diffusion and the Na/K pump is called the **resting membrane potential**, and will continue until an outside signal affects the cell.

Action Potential

Action potentials are caused when outside signals cause sodium and potassium channels to open, allowing these electrolytes to move more quickly into and out of the cell, and rapidly changing the voltage of the cell.



Initially, sodium gates will open, allowing sodium to enter the cell. Once this voltage reaches the threshold voltage, large numbers of voltage gated channels open. As positive charges enter, the voltage rapidly increases, causing **depolarization**. Once the voltage peaks, sodium gates will close, and potassium gates will open, allowing potassium to exit the cell. As positive charges exit, the voltage will rapidly decrease, causing depolarization.

Neuromuscular Junction

The nerves of the body directly control the skeletal muscle tissues. Motor neurons are responsible for delivering the signals (AP) that will trigger muscle contraction.
The point where the nerve reaches the muscle fiber is called the **neuromuscular junction**. The nerve does not come into contact with the muscle cell, instead leaving a gap called the **synapse**.
The surface of the muscle cell on the other side of the synapse is called the **motor end plate**, and has large quantities of **chemically gated sodium channels**. These channels are designed to open when they receive **acetylcholine** (**ACh**), which is released by the nerve. The areas around the motor end plate contain **voltage gated sodium channels**, which will open when the voltage in the muscle cell increases.
The end of the nerve that forms the neuromuscular junction is called an **axon terminal**. Inside the terminal are vesicles containing ACh. ACh and other chemicals released from nerves are known as **neurotransmitters**. The axon terminal will also contain **voltage gated calcium channels**, which will open when the voltage inside of the nerve increases.

Muscle Contraction

Muscle contraction can be broken down into multiple steps, and can be difficult to remember due to this. To simplify matters, first break the contraction into smaller stages occurring in specific parts of the cell, then look at the individual steps.

Inside the Nerve

- In order for a muscle contraction to occur, first a signal from the brain will be sent down the nerve in the form of an action potential.
- At the axon terminal, the increased voltage from the action potential will cause calcium gates to open, allowing calcium to enter.
- Calcium will bond to vesicles of ACh, causing them to undergo exocytosis and release the ACh into the synapse

Initiation of Action Potential in the Muscle

- When ACh crosses the synapse, it will bond to the chemically gated sodium channels on the motor end plate, causing them to open
- The sodium channels will allow sodium to enter the end plate, increasing the voltage in that area
- As voltage in the motor end plate increase, voltage gated sodium channel adjacent to the end plate will begin to open, allowing additional sodium to enter
- A chain reaction will occur, down the length of the muscle cell, where opening sodium gates leads to an increase of voltage, which then causes additional voltage gates to open.

Effect of Action Potential Inside the Muscle

- The transverse tubules will take in sodium, causing their voltage to increase
- Voltage gated calcium channels within the terminal cisternae will open in response to the change in voltage in the transverse tubules, releasing calcium into the myofilaments

Changes in the Myofilaments

- Calcium will bond to the troponin molecules in the thin filaments, and cause them to twist, pulling the tropomyosin threads to be moved
- Moving the tropomyosin will uncover attachment points (**active sites**) on the surface of the thin filament
- Myosin heads will break up an ATP, using the energy to extend out to the thin filament
- Myosin heads will form a bond called a **crossbridge** with the thin filaments
- Myosin heads will then retract, pulling the thin filaments in toward the midline, in what is called the **power stroke**
- After retracting, the myosin heads will release the thin filament once they replace their ATP, then repeat their sequence of extending, connecting, and retracting.

Ceasing Muscle Contraction

The muscle contraction will continue until the signal from the nerve ceases. When it does, the sequence of events that caused the contraction will come to an end.

- When the action potential in the nerve ends calcium gates close, and calcium stops entering the cell
- Without calcium, ACh stops being released
- The enzyme **acetylcholinesterase** (**AChE**) will remove ACh from the gates on the motor end plate, closing those sodium channels.
- When sodium channels close, voltage in the cell decreases, and the action potential ends
- When the action potential ends, the voltage in the transverse tubule will decrease, closing the calcium channels in the terminal cisternae and causing them to reabsorb calcium
- When calcium is removed from the thin filament, troponin will move the tropomyosin back over the active sites, blocking the connection of the myosin heads and preventing contraction.

Stages of Muscle Contraction

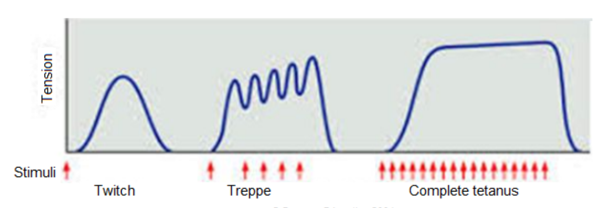
Muscle contraction can be broken into two stages.
Isometric contraction, where the contraction is building up force, but the muscle has not yet contracted and remains its original length.
Isotonic contraction, where once the muscle is exerting enough force to move an object, the muscle begins to contract, while the amount of force remains constant.

Muscle Tension

Muscle tension occurs when a muscle stays contracted or semi-contracted for a long period of time. Each muscle contraction must be caused by a stimulus from the nerve, and will cause a short contraction before ending. By increasing the frequency that the muscle is sent action potentials, the contraction of the muscle can be altered. This allows for longer and more powerful muscle contractions.

A muscle **twitch** occurs when there is enough time for the muscle contraction to complete, and for the muscle to relax before the next stimulus is received.

Treppe occurs when there is insufficient time for relaxation before the next stimulus is received. This causes the following contraction to be added onto the prior contraction, increasing the strength of the contraction.



Complete tetanus occurs when the stimuli are occurring quickly enough that there is no time for relaxation, causing the muscle contraction to be held in a rigid state without any relaxation

Muscle Metabolism

Muscle cells require an enormous amount of energy to function, as every time a myosin head contracts, it uses one ATP. Each thick filament contains huge numbers of myosin heads, while the muscle fiber will have a similarly huge number of thick filaments along their length. To keep up with this energy production, these cells have large numbers of mitochondria to produce ATP.

Energy Production in Muscle

In the muscle cell, there are several different methods used to produce ATP, based on the requirements of the cell.

Aerobic Respiration

Under normal circumstances, the body prefers to use a process called **aerobic respiration**, which uses sugar and oxygen to make energy, with the waste products of water and carbon dioxide. This is the most efficient form of energy production, creating the maximum amount of ATP, while making the fewest wastes. Unfortunately, aerobic respiration is limited by the quantity of oxygen that is available. To increase the amount of usable oxygen, muscles have a protein **myoglobin** that is capable of storing oxygen for later used.

Anaerobic Respiration

When Muscle cells run out of oxygen, they will switch to methods that do not require oxygen for energy production, **anaerobic respiration**. There are two main methods the muscle cells use.

Fermentation is a process that converts sugars into acids. While it does not take much time to complete, it produces less ATP than aerobic respiration, and produces acids as wastes, which impair the muscles ability to work.
Enzymes allow muscle cells to directly convert ADP back into ATP, without needing to be sent to the mitochondria. These enzymes however are only able to convert a small number of ADP molecules, and produce large amounts of toxic waste products.

Normal Sequence of Energy Sources

In normally functioning muscle tissue, energy production methods will alternate based on the demands for energy, and the available supply of materials.

1. Aerobic respiration will begin, and continue until the oxygen received from the blood and myoglobin is exhausted.
2. Anaerobic respiration will start, producing energy to maintain muscle activity. Enzymes will be used to produce energy if fermentation cannot keep up with demand.
3. As heart rate and blood pressure increase during exertion, additional oxygen carrying blood will be delivered to the muscles, allowing for aerobic respiration to resume.

Classes of Muscle Fibers

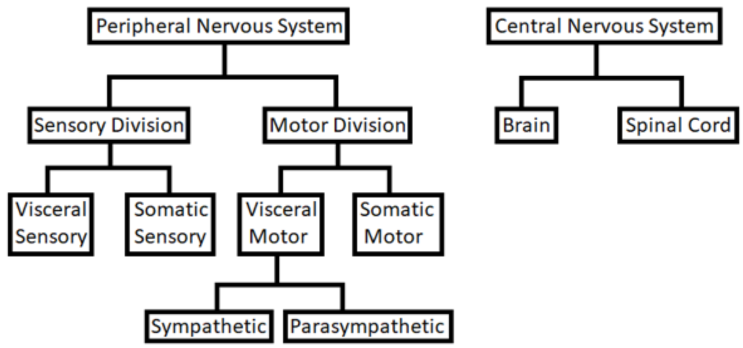
Muscle fibers can be categorized by the type of energy production they specialize in using.
Slow oxidative muscle fibers rely primarily on aerobic respiration. These muscle cells have large supplies of myoglobin and mitochondria, and usually have a darker color. Since aerobic respiration is very efficient, these muscle cells do not fatigue easily. These muscle fibers specialize in long duration activity
Fast glycolytic muscle fibers rely primarily on anaerobic respiration. These muscle fibers contain large quantities of enzymes, and have a sarcoplasmic reticulum that is capable of releasing and reabsorbing calcium more quickly than those in SO muscle fibers. These muscle fibers specialize in fast response, low duration movement.

Nervous Tissue and the Nervous System

The nervous system and the endocrine system are the organ systems responsible for control and coordination of the body. The nervous system operates using electrochemical signals to gather information and send commands to the tissues and organs of the body.

Divisions of the Nervous System

The nervous system is divided into two main branches, the **central nervous system** composed of the **brain** and **spinal cord**, and the **peripheral nervous system** composed of the nerves of the rest of the body.



The peripheral nervous system can be broken into the **sensory division** which transmits signals towards the central nervous system, and the **motor division** which transmits signals from the central nervous system to the body.

Within the peripheral nervous system, there are nerves which transmit information to and from the organs. The signals from **visceral nerves** are not reported to the conscious mind, leaving us unaware of this information. The nerves which transmit and receive signals from the conscious mind form the **somatic nerves**. These nerves receive sensory signals from body organs, and control the skeletal muscles.

The **visceral motor division** of the peripheral nervous system is also known as the **autonomic nervous system**, and is responsible for maintaining the function of the organs. The **parasympathetic nervous system** controls normal functions such as digestion and maintaining circulation. The **sympathetic nervous system** is activated in emergency situations, and is sometimes called the **fight or flight response**, which focuses on supplying the muscles with blood and oxygen to allow a person to flee or fight off danger.

Nerve Tissue

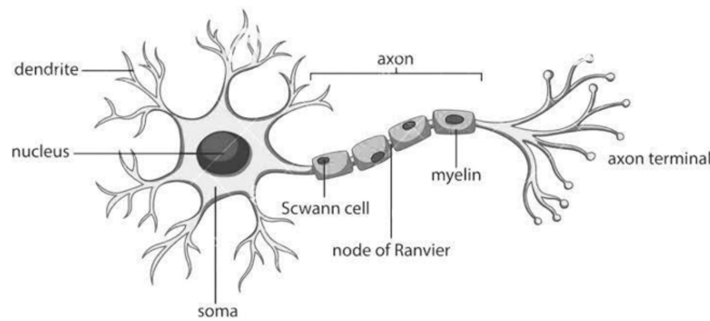
Nerve tissues are composed of **neurons** (nerve cells) and **neuroglia** (supporting cells).

Neurons

Neurons are often described by the direction they send their information.

- **Sensory neurons**, also called **afferent** neurons, send information from the body to the CNS
- **Motor neurons**, also called **efferent** neurons, send information from the CNS to the body
- **Interneurons** are special neurons found only in the central nervous system. These neurons create networks that allow for processing of information

When looking at a neuron, the cell body or **soma** is surrounded by a set of small projections called **dendrites**. Neurons have a large rough endoplasmic reticulum, which is divided into smaller portions called **nissl bodies** by a network of microtubules and **neurofibrils** composed of actin fibers.



The cell will narrow down forming the **axon hillock**, which will extend into a long fiber called the **axon**. The ends of the axon will branch out, forming **axon terminals** that will form synapses with other cells. The axon is surrounded by segments of **myelin**, which acts as an insulator, speeding up action potentials. Sections of the axon covered by myelin are called **internodes**, and are separated by small unmyelinated sections called **nodes of Ranvier**

The dendrites of the neutron are used to receive signals from other cells, and will initiate an action potential that will pass down to the soma, before passing down the axon.

Classifications of Neurons

There are several variations of neurons, which are identified by the number of processes coming off of the soma

- **Multipolar neurons** have one axon and multiple dendrites. Most common neuron
- **Bipolar neurons** have one axon and one dendrite. Found in sensory organs.
- **Unipolar neurons** have a single process connecting to the axon. The axon of these cells will have dendrites on one end and axon terminals on the other. Found in the sensory nerves of the peripheral nervous system.
- **Anaxonic neurons** have multiple dendrites and no axon, do not produce action potentials. Found in the brain, retina and adrenal medulla.

Neuroglia

Neuroglia are the supporting cells that protect, supply, and assist the neurons. There are different neuroglia in the peripheral nervous system compared to central nervous system

Neuroglia of the PNS

In the peripheral nervous system there are two types of neuroglia

- **Schwann cells** produce the myelin sheaths that cover the axons of the neurons in the PNS. Each myelin sheath is composed of one Schwann cell that has wrapped itself around the axon.
- **Satellite cells** surround the soma of neurons in the PNS. These cells help protect the neuron, and will deliver oxygen and nutrients to the neurons, protecting them from direct contact with the contents of the blood.

Neuroglia of the CNS

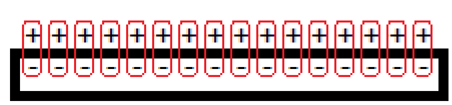
In the central nervous system there are four types of neuroglia.

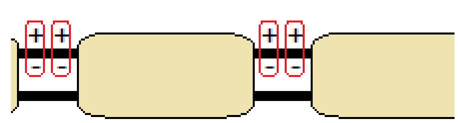
- **Oligodendrocytes** produce the myelin sheaths for axons in the CNS. Unlike Schwann cells, they produce these sheaths by extending processes to nearby axons, with each process forming a single myelin sheath.
- **Astrocytes** have several functions. They surround the blood vessels in the brain, preventing substances from easily entering the brain in order to prevent disease causing organisms or toxins from entering the CNS. This function is sometimes called the **blood-brain barrier**. The astrocytes will also connect to the neurons and other cells in the CNS, and deliver oxygen and nutrients, as well as removing wastes from them. Due to their connections, astrocytes also help create and support the structures found in the CNS.
- **Microglia** are a type of immune cell called a **macrophage**. These cells will circulate around the cells of the CNS, looking for signs of infection, and **phagocytizing** (swallowing up) any disease causing organisms they find.
- **Ependymal cells** produce **cerebrospinal fluid**, which fills the cavities and surrounds the brain and spine. This fluid cushions impacts, preventing damage to the CNS

Effect of Myelin on Axon

As stated earlier, myelin has the effect of speeding up action potentials in the neuron. To understand how this functions, first consider an unmyelinated axon.

If every red box represents an ion gate in this figure, in order to send an action potential, each gate needs to be opened in sequence.





In this figure, the yellow portions represent myelin sheaths, covering many ion gates. This will cause the action potential to jump myelinated sections
Since there are fewer ion gates to operate in myelinated neurons, signals will be able to pass along them far faster than unmyelinated neurons.

Neurotransmitters

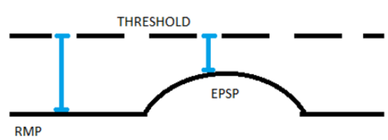
Neurotransmitters are chemicals created by the neuron and released from their axons. These chemicals are used to pass signals to the cell that has a synapse with the neuron. There are over 100 known neurotransmitters, which all have different purposes and trigger different responses in the body. Neurons are generally categorized as follows:

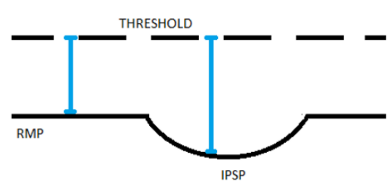
- **Acetylcholine** is formed from acetic acid and choline. It generally has an excitatory effect on cells.
- **Amino acids** include glutamate and aspartate, which have excitatory effects in the CNS, as well as glycine and GABA, which have inhibitory effects in the CNS
- **Monoamines** are formed by removing the carboxyl groups from amino acids. Some examples are epinephrine, dopamine, and norepinephrine, which have powerful effects on the circulatory system
- **Neuropeptides** are short chains of amino acids. These tend to work in lower concentrations, and longer durations than other neurotransmitters.

Postsynaptic Potentials

Postsynaptic potentials refer to the effects that a neurotransmitter has when it is released onto a cell.

- **Excitatory postsynaptic potentials** (**EPSPs**) increase the voltage in the target cell. This may start an action potential, or may make it easier to start an action potential by bringing the cell closer to the threshold voltage
- **Inhibitory postsynaptic potentials** (**IPSPs**) decrease the voltage in the target cell. This serves to make it more difficult to start an action potential by dropping the cell's voltage farther from the threshold voltage.

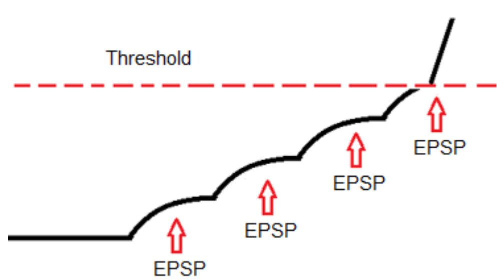




Summation

Summation is the concept of combining multiple signals that on their own are not enough to create an action potential into a single single that can trigger an action potential.

If a cell receives a new EPSP before the previous one has ended, the effects of the two are combined. If additional EPSPs are added, it can bring the voltage of the cell above the threshold voltage, triggering an action potential.



Summation can occur in two primary ways:

- **Spatial summation** involves receiving multiple signals from multiple sources in a short period of time.
- **Temporal summation** involves receiving multiple signals sent from a single source in a short period of time.

The Spinal Cord

The spinal cord is a collection of nerves that carry signals from the brain to the body, and from the body to the brain. The spinal cord carries out three main functions:

- **Conduction** of signals along nerves between the body and the brain
- **Locomotion** by taking input from the brain and initiating and regulating repetitive muscle contractions responsible for moving the legs and feet.
- **Reflexes** are involuntary responses to stimuli designed to reduce damage to the body

Surface Anatomy

The spinal cord is a cylindrical mass of nervous tissue running from the brainstem where it passes through the foramen magnum, down through the vertebral canal until the first lumbar vertebra. Below this level the spinal cord splits into the **cauda equina**, a bundle of nerve roots which pass through the vertebral column until the fifth sacral vertebra.
The spinal cord is divided into the **cervical**, **thoracic**, **lumbar**, and **sacral** regions, named for the level of the vertebral column from which their spinal nerves extend from.

There are two regions of the spinal cord where the cord is thicker than normal, the **cervical enlargement** which produces the nerves of the upper limbs, and the **lumbar enlargement**, which produces the nerves of the pelvic region and lower limbs.

Meninges

The **meninges** are a set of three fibrous connective tissue membranes that cover the brain and spinal cord. The meninges protect the delicate nervous tissue from abrasion and damage from the bones that line the cranial and vertebral columns. Additionally the spaces of the meninges are filled with cerebrospinal fluid, which helps cushion impacts.

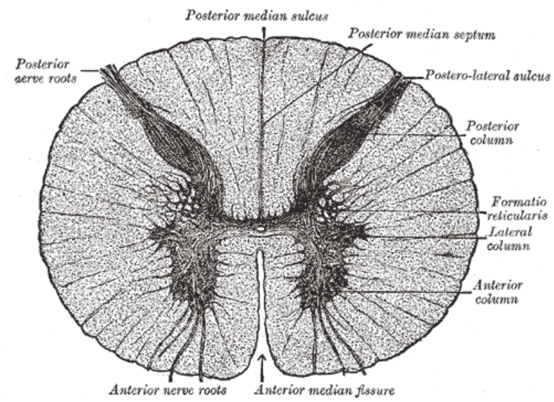
The three layers of meninges from deepest to most superficial are:

- The **pia mater** is a thin translucent membrane that follows the surfaces of the brain and spinal cord.
- The **arachnoid mater** is a simple squamous epithelium attached to the inner surface of the dura mater, connected to a mesh-like network of collagen and elastic fibers that connect the to pia mater.The area between the arachnoid mater and the pia mater is called the **subarachnoid space**.
- The **dura mater** is a thick sheath of collagen fibers that loosely fits around the brain and spinal cord. The space between the durmater and the bones that form the cranial and vertebral columns is called the **epidural space**.

Cross-sectional Anatomy

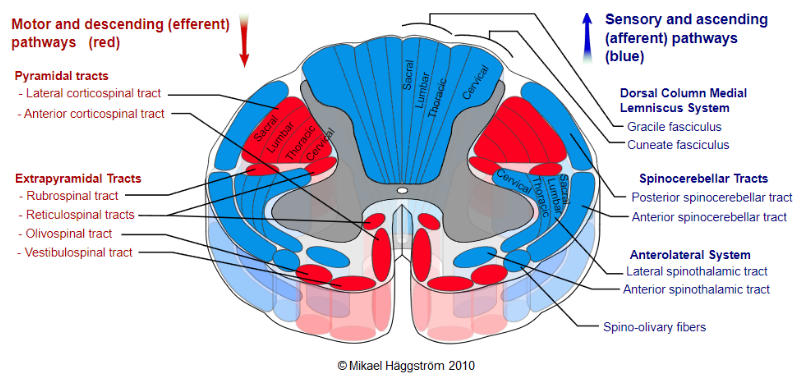
The spinal cord is composed of two types of nervous tissue, myelinated **white matter**, and mostly unmyelinated **gray matter**.
Gray matter consists of the soma, dendrites, and proximal portions of neurons, and is the site where synapses between neurons occur.
White matter consists of myelinated axons, traveling in groups called **tracts**.

In the cross section of the spinal cord, the gray matter forms an “H” shape, formed of the **anterior horns**, **posterior horns**, and the **gray commissure**.In the spinal cord from the second thoracic vertebra until the first lumbar vertebra there will be an additional **lateral horn**, which extends laterally from the gray matter. The lateral horn carries neurons of the sympathetic nervous system.
In the middle of the gray commissure is a small open space called the **central canal**.



Spinal Tracts

The spinal tracts are bundles of nerves carrying signals up and down the spinal cord. **Ascending tracts** carry sensory neurons delivering signals from the body to the brain. **Descending tracts** carry motor neurons delivering signals from the brain to the body.

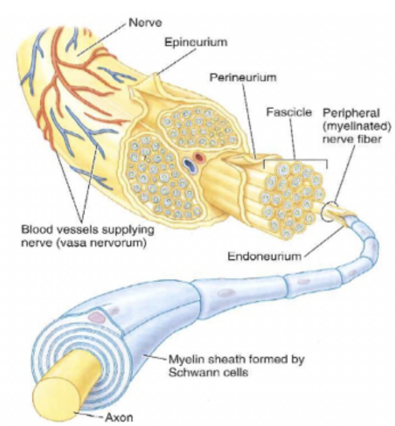


Spinal Nerves

Spinal nerves are nerves that originate from the spinal cord and exit the vertebral column through the intervertebral foramina before traveling to the portion of the body they innervate.

Nerve Anatomy

A nerve is a group of axons traveling together, each of which is surrounded by a membrane called the **endoneurium**. These groups of axons will be wrapped up in the **perineurium**, forming a **fascicle**. Groups of fascicles and blood vessels will be wrapped in an outer membrane called the **epineurium**, forming a nerve



Proximal Branches

Spinal nerves will originate from the anterior and posterior lateral edges of the spinal cord. At each of these regions, six to eight **rootlets** will exit the spinal cord before fusing to form the **posterior root** which carries sensory neurons, and the **anterior root** which carries motor neurons. The posterior root will expand, forming the **posterior root ganglion** which is the site where sensory nerves from the PNS form synapses with sensory nerves from the CNS. After the posterior root ganglion, the anterior and posterior roots will fuse to form the spinal nerve.

Somatic Reflexes

Reflexes are rapid involuntary actions that will cause the spine to directly activate muscles or glands in response to certain types of sensory input. Reflexes will occur very quickly, as they require few interneurons, and low transmission time. Reflexes are involuntary, not requiring input from the brain. Reflexes will alway trigger the same response to a given stimulus.

Somatic reflexes are described as following a series of steps, called the **reflex arc**.

1. Somatic receptors trigger, sending a signal down a sensory neuron
2. In the spine, an interneuron will respond to certain stimuli and trigger the response
3. Motor neurons carry a signal to a skeletal muscle which will contract

Stretch Reflex

Stretch reflexes are triggered when skeletal muscles are put under tension and stretched out. This will trigger **proprioceptors**, receptors that monitor the position and movement of the body, sending a signal through a sensory nerve. Unlike the following reflexes, stretch reflexes are mostly managed by the brain, allowing for the coordination of multiple muscle groups. Some responses are managed by the spine, and will occur even if the connection to the brain has been severed.
Stretch reflexes are important for maintaining posture and smoothing muscle movements.

Flexor Reflex

The **flexor**, or **withdrawal reflex** is triggered in response to injury. Once sensory nerves carry the signal to the spine, it will trigger multiple interneurons in order to create motor signals to cause flexion in the muscles on the side of the body the injury was detected on, and extension on the other side of the body.

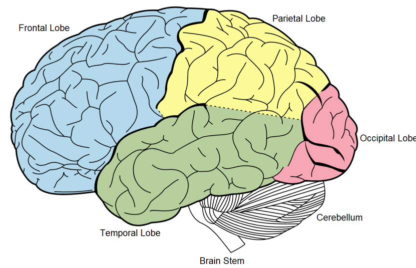
Tendon Reflex

Tendon reflexes are triggered by proprioceptors in the tendons which connect muscles to the bones. When muscle contractions cause the tendons to stretch, it will trigger a sensory nerve signal that will cause the spinal cord to inhibit motor neurons that connect to that tendon’s muscle, reducing the force of contraction and relieving strain on the tendon.

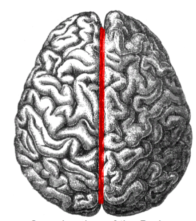
The Brain

The brain is the most complex structure of the nervous system, enabling consciousness, processing sensory information, generating muscle output, and many other functions.

Gross Anatomy



The brain is divided into three major portions, the **cerebrum**, the **cerebellum**, and the **brainstem**. The cerebellum can be divided into four lobes, corresponding with the bones of the skull that cover them: the **frontal lobe**, the **parietal lobe**, the **temporal lobe**, and the **occipital lobe**. On the surface of the brain there are raised ridges called **gyri**, and depressed valleys called **sulci**.

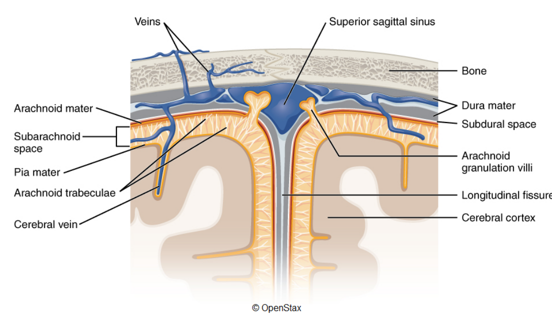

Superior view of the Brain with lateral fissue highlighted

The brain also has deep grooves which separate areas of brain tissue called fissures. The right and left hemispheres of the cerebrum are separated by the **longitudinal fissure**, with a thinner layer of nerve tissue called the **corpus callosum** connecting the two hemispheres.

The cerebellum is located inferior to the cerebrum, and makes up about 10% of the volume of the brain. Despite this, it holds half of the total neurons.

The brainstem makes up the remaining areas of the brain, and is composed of the **diencephalon**, **midbrain**, **pons**, and **medulla oblongata**.

Meninges

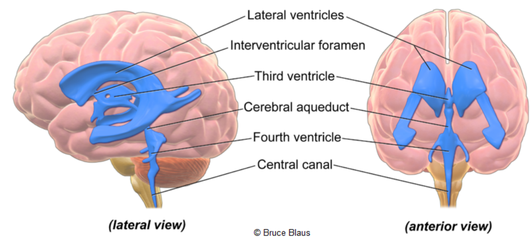


As discussed in the spine section, the brain is similarly covered by the meninges. One difference is that there is a second layer of dura mater which lines the bones of the cranium, and is called the **periosteal layer** of the dura mater. The Inner **meningeal layer** of the dura mater usually is connected to the outer layer, but will have some areas that form spaces between the layers, forming the **dural sinuses** where blood vessels can be found.
In some areas of the cranium, there is a space between the dura mater and arachnoid mater, called the **subdural space**. In some areas the arachnoid mater will pass through openings in the dura mater called the **arachnoid villi**, into the dural sinuses.

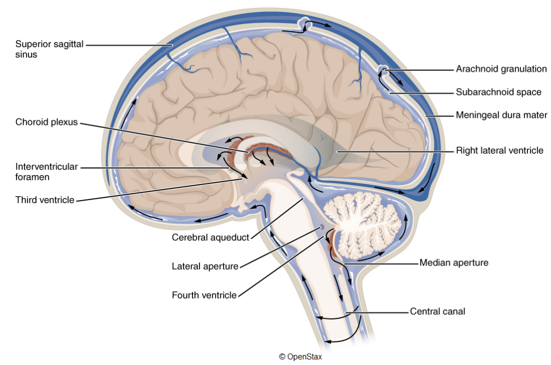
The pia mater will follow the surface contours of the brain, entering the sulci, while the arachnoid mater and dura mater do not. The arachnoid and dura mater however do enter into the major fissures of the brain, forming the **falx cerebri** in the longitudinal fissure, and the **tentorium cerebelli** between the cerebrum and cerebellum.

Ventricles and Cerebrospinal Fluid

The brain contains four cavities called **ventricles**. The ventricles will contain the **choroid plexus** which are a series of blood vessels that supply the ependymal cells as they produce the cerebrospinal fluid.



CSF will flow from the **lateral ventricles**, through the **interventricular foramen**, into the **third ventricle**, then through the **cerebral aqueduct** to the **fourth ventricle**. From the fourth ventricle, CSF will exit through the **median** and **lateral apertures**, entering the subarachnoid space. The CSF will flow throughout the CSF, before passing through the arachnoid villi into the dural sinuses, where blood vessels will absorb the CSF.



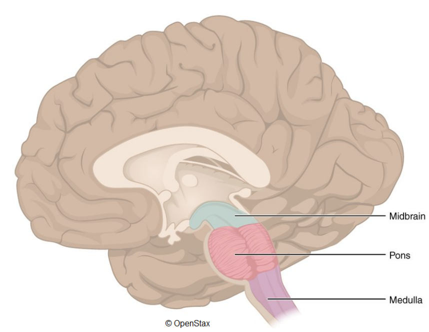
Structures of the Brain

In this section, we will look at the different physical structures of the brain and briefly discuss their functions.

Brainstem

Medulla Oblongata

The medulla oblongata originates from the foramen magnum, and extends upward for about 3cm where it meets the pons.



All nerves connecting the brain to the spinal cord pass through the medulla oblongata. The medulla contains neural networks that are involved in basic motor functions like chewing, swallowing, respiration and speech; and sensory functions like touch, pressure, pain, and taste. The medulla also contains a **cardiac center** which regulates the heartbeat, a **vasomotor center** which regulates blood pressure, and two **respiratory centers** which regulate the rate and rhythm of breathing.

The medulla is the origin of four cranial nerves, the **glossopharyngeal nerve (IX)**, **vagus nerve (X)**, **accessory nerve (XI)**, and **hypoglossal nerve (XII)**.

Pons

The pons is located on top of the medulla oblongata, and appears as a broad anterior bulge, with two **cerebellar peduncles** on its posterior surface. The pons contain nerves that help regulate sleep, respiration, and posture.

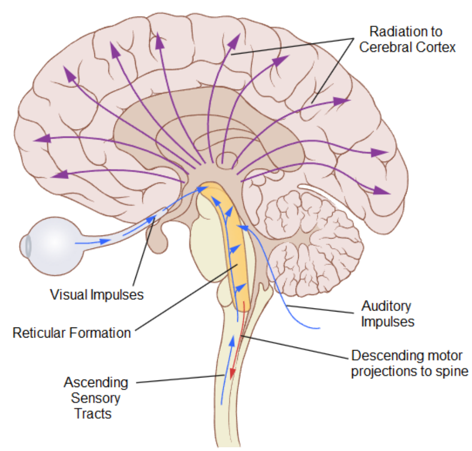
The pons is the origin of four cranial nerves, the **trigeminal nerve (V)**, the **abducens nerve (VI)**, the **facial nerve (VII)**, and the **vestibulocochlear nerve (VIII)**.

Midbrain

The midbrain is a short section that connects the brainstem and the forebrain. The cerebral aqueduct runs through the midbrain.
Posterior to the cerebral aqueduct is the **corpus quadrigemina**, which is made of the two **superior colliculi**, and the two **inferior colliculi**. The superior colliculi are involved in vision, allowing for tracking of moving objects, and controlling the blink reflex. The inferior colliculi relays signals from the ears to other regions of the brain, and is responsible for the startle reflex that causes a person to jump in response to loud noise.
Anterior to the cerebral aqueduct are the cerebral peduncles, which anchor the brainstem to the cerebrum. Nerves in the cerebral peduncles are involved in preventing unwanted muscle movement, preventing tremors.

The midbrain is the origin of two cranial nerves, the **oculomotor nerve (III)** and the **trochlear nerve (IV)**.

Reticular Formation



The **reticular formation** is a network of gray matter that runs vertically through the brain stem. It takes up the spaces between the white matter tracts, and has connections to many areas in the cerebrum. Its neural networks control:

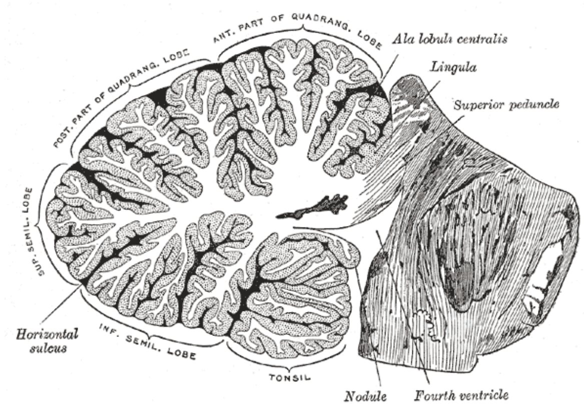
- **Somatic motor control** due to **reticulospinal tracts** in the spinal cord that adjust muscle contractions to maintain balance, posture, and muscle tone.
- **Cardiovascular control** through the cardiac and vasomotor centers of the medulla oblongata
- **Pain perception** through sensory nerves that deliver pain signals from the body, and the **descending analgesic pathways** which can block transmission of pain signals to the brain.
- **States of consciousness** due to projections to the thalamus and cerebral cortex, that allow the reticular formation to control what sensory information is delivered to conscious perception
- **Filtering stimuli** by filtering what it perceives as repetitive unimportant sensory information from conscious perception.

Cerebellum

The cerebellum is located below the cerebrum, and is mostly separated into a right and left hemisphere separated by the **falx cerebelli**, with the **vermix** connecting the hemispheres. The surface of the cerebellum is covered in **folia**, a series of parallel folds separated by sulci.

The cerebellum is primarily composed of gray matter, with a deep, branching section of white matter. In a sagittal section, the white matter forms a branching pattern called the **arbor vitae**. The tightly packed gray matter means there is a huge number of neurons in the cerebellum, accounting for more than half of all the neurons in the brain.

The cerebellum is connected to the brain stem by three sets of cerebellar peduncles. The **inferior peduncles** connect to the medulla and provide the cerebellum with most of its sensory input. The **medial peduncles** connect to the pons, and provide the remainder of the sensory input from the rest of the brain. The **superior peduncles** connect to the midbrain, and carry motor signals from the cerebellum.



The cerebellum is involved in motor coordination, evaluates sensory inputs, assists in recognizing spatial relationships, and is involved in maintaining the sense of time.

Diencephalon

The diencephalon encloses the third ventricle and is the highest portion of the brainstem

Thalamus

The **thalamus** is an oval shaped area attached to the superior end of the brainstem. They extend laterally from the third ventricle to the lateral ventricles. The thalamus is divided into five sets of nuclei.

- The **anterior group** is part of the limbic system, and is involved in memory and emotion
- The **medial group** delivers emotional output to the prefrontal cortex, and is involved in perception of emotions
- The **ventral group** is involved in transmission of sensory information to the cerebrum, and transmission of motor output from the cerebellum to the cerebrum.
- The **lateral group** is involved in sensory association, and assists in emotional function of the limbic system.
- The **posterior group** is involved in the transmission of visual signals to the occipital lobe, and auditory signals to the temporal lobe.

Hypothalamus

The **hypothalamus** forms the inferior surface of the third ventricle. The **pituitary gland** is connected to the hypothalamus through the **infundibulum**.
The hypothalamus is a control center of the autonomic nervous system and the **endocrine system**. It controls homeostasis in most body systems and organs. Some of the major functions of the hypothalamus are:

- Secretion of hormones that control the pituitary gland, and production of hormones throughout the body

- Control of heart rate, blood pressure, digestive function, and others through the autonomic nervous system.
- Control of body temperature
- Control of hunger and thirst
- The sleep cycle, and feelings of tiredness
- The hypothalamus is involved in accessing memory, due to its forming the connection between the thalamus and **hippocampus**.
- Involved in emotional responses

Cerebrum

The cerebrum is the largest structure of the brain. It has five lobes, four of which are visible and have been previously described.

- The frontal lobe is the forwardmost portion of the brain, and extends back to the **central sulcus**. The frontal lobe is involved in motor control, motivation, planning, memory, mood, judgment, and aggression.
- The parietal lobe forms the uppermost portion of the brain, originating from the central sulcus and extending back to the **parieto-occipital sulcus**, and downard to the **lateral sulcus**. The parietal lobe is involved in receiving and processing general sensory signals, as well as the sense of taste.
- The occipital lobe forms the rear of the cerebrum, originating from the parieto-occipital sulcus, and extending to the occipital bone. The occipital lobe is involved in the sense of sight, processing visual signals and visual memory.
- The temporal lobe is located on the lateral surface of the cerebrum, and is separated from the parietal lobe by the lateral sulcus. The temporal lobe is involved in the senses of hearing and smell, learning, and memory.
- The fifth lobe is the **insula**, located deep to the lateral sulcus that separates the parietal and temporal lobes. It is involved in understanding spoken language.

Cerebral White Matter

The majority of the cerebrum is composed of white matter. This white matter forms three distinct tracts:

- **Projection tracts** extend vertically through the cerebrum to the spinal cord, and carry motor and sensory signals between the cerebrum and the body.
- **Commissural tracts** connect the right and left hemispheres. The majority of these commissural tracts pass through the corpus callosum.
- **Association tracts** connect different regions within the same hemisphere. **Long association fibers** connect areas in different hemispheres together, while **short association fibers** connect different gyri in the same hemisphere together.

Cerebral Cortex

The cerebral cortex is the layer of gray matter that covers the surface of the cerebrum. This layer is approximately 3mm thick, but makes up 40% of the mass of the brain. The majority of the cerebral cortex is a six layer section called the **neocortex**. This is one of the major regions where neutral integration (connections between neurons) occurs.

Basal Nuclei

The basal nuclei are sections of gray matter located lateral to the thalamus. There are several groups of basal nuclei, including the **caudate nucleus**, **putamen**, and **globus pallidus**. These areas are involved in motor control

Limbic System

The limbic system is the center of emotion and learning. It is formed by the **caudate gyrus**, which is superior to the corpus callosum, and the hippocampus and the amygdala in the temporal lobe. These regions contain gratification which create a sense of pleasure and aversion centers which produce uncomfortable sensations like fear and sorrow.

Functions of the Brain

Sleep

Sleep is a temporary state of unconsciousness that occurs in cycles called the **circadian rhythm**. During sleep, muscular activity is inhibited, causing **sleep paralysis**. Sleep occurs in cycles of five stages:

- **Stage 1** - causes drowsiness. The eyes close and the mind relaxes. Can be easily woken
- **Stage 2** - beginning of light sleep, brain activity slows
- **Stage 3** - moderate to deep sleep. Occurs 20 minute after stage 1 sleep. Muscles relax and vital signs decrease.
- **Stage 4** - Muscles are very relaxed, vital signs reach lowest levels. Very difficult to wake from at this stage.
- **Rapid eye movement (REM) sleep** - Eyes rapidly move, brain activity resembles waking levels, sleep paralysis becomes stronger and vital signs increase. Waking is most difficult during this stage.

Dreaming can occur both during REM and non-REM sleep.

Cognition

Cognition describes all of the mental processes that occur as we gain and use knowledge.This includes perception, thought, reasoning, judgment, memory, imagination, and intuition. Cognition is one of the least understood cerebral functions, and is the most researched area of brain function.

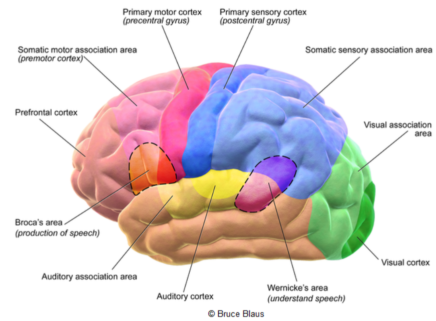
Memory

Memory is a cognitive function, and involves learning, storing and retrieving information, and forgetting information that is no longer needed. The hippocampus plays an important role in organizing memories and experiences into long-term memory. The process of converting shorter term memory into long-term memory is called **memory consolidation**.

Emotion

Emotional feeling and memory is a result of interactions between the **prefrontal cortex** and diencephalon. The prefrontal cortex is used for judgment, forms intent, and controls expression of emotion. The feelings and emotion moderated by the prefrontal cortex originate from the amygdala and hypothalamus. The amygdala receives sensory inputs, and associates emotional responses to them, such as unpleasant odors creating feelings of disgust.

Sensation



Sensation originates from the **primary sensory cortex**, which receives sensory input and converts it into stimuli the conscious mind is aware of. **Sensory association areas** will interpret these stimuli, associating it with concepts and memories.

Special Senses

- Visual signals are received by the **primary visual cortex**, and interpreted by the **visual association area** of the occipital lobe.
- Hearing signals are received by the **primary auditory cortex** and interpreted by the **auditory association area** of the temporal lobe.
- Signals regarding balance and sense of motion are sent from the inner ear to the cerebellum
- **Gustatory** (taste) signals are received by the **primary gustatory cortex** located in the parietal lobe and insula. **Olfactory** (smell) signals are received by the **primary olfactory cortex** located in the temporal and frontal lobes. The **orbitofrontal cortex** interprets signals associated with taste and smell.

General Senses

The general senses are routed by the thalamus to the **primary somesthetic cortex**, located in the **postcentral gyrus** of the parietal lobe. Posterior to this is the **somesthetic association area**, which will interpret this sensory information.

Motor Control

Motor control begins with the intention to move, which occurs at the **motor association area** of the frontal lobes. Neurons in this area will create a program of what signals to send in order to achieve the desired motion. This program is transmitted to the **primary motor cortex**, located in the **precentral gyrus**, which will use this program and send out motor signals to the body.

Language

Language includes reading, writing, speaking, and understanding words. The **Wernicke area** in the parietal and temporal lobes will recognize written and spoken language, by interpreting auditory and visual signals. In order to speak, the **Broca area** in the prefrontal cortex will generate a motor program, which will be implemented by the primary motor cortex.
Wernicke and Broca areas are usually located in the left hemisphere of the cerebrum. On the other hemisphere will be the **affective language area**, which controls the emotional aspect of language.

Lateralization

Lateralization describes the differences in function between the right and left hemispheres of the cerebrum.
Functions associated with the left hemisphere include:

- Olfaction of the right nasal cavity
- Verbal memory, speech
- Right hand motor control
- Feeling shapes with right hand
- Hearing vocal sounds
- Rational and symbolic thought
- Language comprehension
- Right field vision.

Functions associated with the right hemisphere include:

- Olfaction of the left nasal cavity
- Memory of shapes
- Lack of speech control
- Left hand motor control
- Feeling shapes with left hand
- Hearing non-vocal sounds
- Intuitive, non-verbal thought
- Recognition of faces and spatial relationships
- left field vision

Cranial Nerves

The Cranial nerves are 12 sets of nerves that originate from the brain. Some of these nerves are purely sensory or motor, carrying information to the brain or commands to the body, while others are mixed and perform both functions.

Name and Number	Type	Function
Olfactory (I)	Sensory	Sense of Smell
Optic (II)	Sensory	Sense of Sight
Oculomotor (III)	Motor	Controls Medial, Superior Medial, Superior Lateral, and Inferior Lateral eye movement. Opening of eyelid, pupil constriction and focusing
Trochlear (IV)	Motor	Controls Inferior Medial eye movement
Trigeminal (V)	Mixed	Ophthalmic branch- Sensory information from upper face Maxillary branch- Sensory information from middle region of face Mandibular branch- Sensory information from lower face, Controls chewing (mastication)
Abducens (VI)	Motor	Controls Lateral eye movement
Facial (VII)	Mixed	Sensory- Taste from anterior 2/3 of tongue Motor- Facial expressions, secretion of tears, saliva, mucus
Vestibulocochlear (VIII)	Sensory	Sense of hearing and balance
Glossopharyngeal (IX)	Mixed	Sensory- taste from posterior 1/3 tongue, sensation of tongue. Collects information for regulation of blood pressure and respiration Motor- Salivation, swallowing, gagging
Vagus (X)	Mixed	Sensory- Sense of taste, sensation of hunger and fullness, sense of gastrointestinal discomfort Motor- Swallowing, speech, control of heart rate, bronchoconstriction (narrowing of airways), control of stomach and small intestine
Accessory (XI)	Motor	Swallowing, movements of head, neck, shoulder
Hypoglossal (XII)	Motor	Movement of tongue (speech and chewing), swallowing

The Autonomic Nervous System

The autonomic nervous system is the visceral motor division of the peripheral nervous system. It controls cardiac muscle, smooth muscle, and glands in the body. The ANS functions involuntarily and usually without a person's awareness that it is operating.

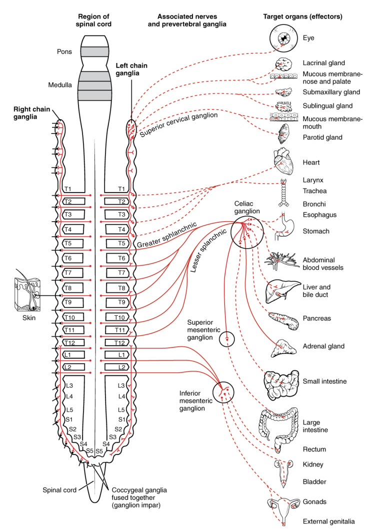
Visceral Reflexes

The ANS is responsible for the visceral reflexes. These are similar to the somatic reflexes, but occur in tissues managed by the ANS. These reflexes perform functions such as lowering blood pressure when blood vessels begin to expand due to increased blood pressure, and accelerating heart rate when blood pressure drops below normal.

Neural Pathways

The autonomic nervous system receives signals from the central nervous system, before sending commands out through its own motor neurons. This requires a synapse between a neuron of the CNS and a neuron of the ANS outside of the spinal cord. When a nerve makes a synapse, a ganglion will form around the cell bodies. Due to this, we sometimes refer to the neuron coming from the CNS as the **preganglionic neuron** and the neuron from the ANS as the **postganglionic neuron**.
Preganglionic neurons are myelinated, while postganglionic nerves are unmyelinated.
Preganglionic neurons will all release acetylcholine in order to signal the postganglionic nerve, while postganglionic nerves will either release ACh or norepinephrine.

Sympathetic Nervous System



The preganglionic nerves that signal the sympathetic nervous system originate from the thoracic and lumbar vertebrae.

The sympathetic nervous system has very short preganglionic nerves, with ganglia forming on either side of the vertebral column, creating a structure called the **sympathetic chain** ganglia. From these ganglia, unmyelinated neurons will proceed to their respective organs.

The adrenal medulla is the only organ controlled by the sympathetic nervous system that has a long preganglionic nerve. The synapse with the postganglionic nerve occurs within the adrenal medulla. The adrenal medulla will secrete epinephrine, norepinephrine, and dopamine when signaled by the sympathetic nervous system

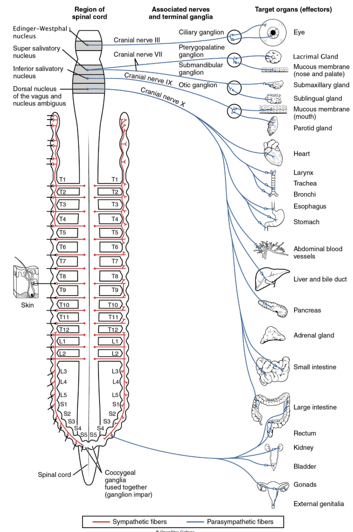
The sympathetic nervous system when activated will increase blood pressure, heart rate, and respiratory rate, while diverting blood flow away from the digestive and urinary systems. This serves to maximize the amount of oxygenated blood being sent to the skeletal muscles, enabling a person to successfully fight off an attacker, or flee from danger.

Parasympathetic Nervous System

The preganglionic nerves that signal the parasympathetic nervous system originate from the brain and the sacral region of the spinal cord.

The parasympathetic nervous system tends to have very long preganglionic fibers, with ganglia formed near the target organs, causing there to be shorter postganglionic neurons.

The parasympathetic nervous system is responsible for maintaining the regular function of the digestive and urinary systems, as well as maintaining normal blood pressure.



Autonomic Control

In order to control their targets, the postganglionic cells of the ANS will release neurotransmitters that will cause different effects on their targets.

Nerve fibers that release ACh are referred to as **cholinergic fibers**. All presynaptic fibers are cholinergic. All postsynaptic parasympathetic nerve fibers, as well as some postsynaptic sympathetic fibers, are cholinergic.

Any receptor that will bond ACh is called a **cholinergic receptor**. There are two different types of cholinergic receptors. **Muscarinic receptors** in the cardiac muscle will create an inhibitory response (IPSP), while in the smooth muscle of the intestines it will cause an excitatory response (EPSP). **Nicotinic receptors** will always create an excitatory response (EPSP).

Nerve fibers that release norepinephrine (NE) are referred to as **adrenergic fibers**. Most postganglionic sympathetic fibers are adrenergic.

Any receptor that will bond NE is called an **adrenergic receptor**. There are also two different types of adrenergic receptors. **α (alpha) adrenergic receptors** are usually excitatory, except in the intestines, where it inhibits intestinal motility (ability to move material). There are two subtypes of α receptors, α1 and α2. **β (beta) adrenergic receptors** are usually inhibitory, except in the heart where it has an excitatory effect. There are also two subtypes of β receptors, β1 and β2.

Target Organ	Sympathetic Effect and receptor type	Parasympathetic Effect
Eye		
Iris	Pupillary dilation (α)	Pupillary constriction
Ciliary muscle and lens	Relaxation for far vision (β)	Constriction for near vision
Lacrimal (tear) gland	none	Secretion
Integumentary system		
Merocrine sweat glands	Secretion (muscarinic)	No effect
Apocrine sweat glands	Secretion (α)	No effect
Piloerector muscles	Hair erection (α)	No effect
Adipose tissue	Decreased fat breakdown (α) Increased fat breakdown (α,β)	No effect
Adrenal medulla	Hormone secretion (nicotinic)	No effect
Circulatory system		
Heart rate and force	Increased (β)	Decreased
Deep coronary arteries	Vasodilation (β) Vasoconstriction (α)	Slight vasodilation
Blood vessels of most viscera	Vasoconstriction (α)	Vasodilation
Blood vessels of skeletal muscle	Vasodilation (β)	No effect
Blood vessels of skin	Vasoconstriction (α)	Vasodilation, blushing
Platelets (blood clotting)	Increased blotting (α)	No effect
Respiratory system		
Bronchi and bronchioles	Bronchodilation (β)	Bronchoconstriction
Mucous glands	Decreased secretion (α) Increased secretion (β)	No effect
Urinary system		
Kidneys	Reduced urine output (α)	No effect
Bladder wall	No effect	Contraction
Internal urinary sphincter	Contraction, urine retention (α)	Relaxation, urine release

Digestive system		
Salivary glands	Thick mucous secretion (α)	Thin mucous secretion
Gastrointestinal motility	Decreased (α,β)	Increased
Gastrointestinal secretion	Decreased (α)	Increased
Liver	Glycogen breakdown (α,β)	Glycogen synthesis
Pancreatic enzyme secretion	Decreased (α)	Increased
Pancreatic insulin secretion	Decreased (α) Increased (β)	No effect
Reproductive system		
Penile or clitoral erection	No effect	Stimulation
Glandular secretion	No effect	Stimulation
Orgasm	Stimulation (α)	No effect
Uterus	Relaxation (β) Labor contractions (α)	No effect

Dual Innervation

Most organs have nerve fibers from both the sympathetic and parasympathetic divisions. Using both divisions to control the organ is referred to as dual innervation. In these cases, the divisions will either have opposite results (**antagonistic effects)**, or there will be different effects that work together to cause the same end result (**cooperative effects**).
An example of an antagonistic effect would be in the iris, where the sympathetic effect is pupillary dilation and the parasympathetic effect is pupillary constriction. In this case, only one of these effects can occur at a single time.
An example of a cooperative effect is in the mouth, where the sympathetic effect is to produce thick secretions and the parasympathetic effect is to produce thin secretions. The glands of the mouth are capable of producing both of these effects at once, leading to more overall secretion.

Single Innervation

Some organs do not have receptors for both the sympathetic and parasympathetic fibers, but are instead controlled only by the sympathetic nervous system. Examples of these are the adrenal medulla, piloerector muscles, sweat glands, and many blood vessels. In these organs, the sympathetic nerves will send out regular signals called the **sympathetic tone**. When the rate of signaling decreases, the organ will reduce its activity. When the rate of signaling increases, the organ will increase its activity.