قسم التقنيات الاحيائية

مادة : فسلجة حيوان

المرحلة الثانية

الكورس الثاني 2021-2022

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Lecture 1 /---------- Introduction to Physiology

Human physiology is the study of the functioning of the normal body, and is responsible for describing *how* various systems of the human body work. Explanations often begin at a macroscopic level and proceed to a molecular level. Physiology (from the Greek; physis=nature; logos = study). A related science –*Pathophysiology*- is connected with how physiological processes are related in disease or injury. Pathophysiology and the study of normal physiology complement one another.

Scientific method:

The scientific method involves specific steps:

- **Making certain observations regarding the natural world,**
- **A hypothesis is formulated. In order for this hypothesis to be scientific, it must be capable of being refuted by experiments or other observations of the natural world**
- **Experiments are conducted, or other observations are made,**
- **Results are analyzed.**
- **Conclusions are then drawn as to whether the new data either refute or support the hypothesis .**

Extracellular Fluid—the "Internal Environment"

About 60% of the adult human body is fluid, mainly a water solution of ions and other substances. Although most of this fluid is inside the cells and is called *intracellular fluid,* about one third is in the spaces outside the cells and is called *extracellular fluid.* It is transported rapidly in the circulating blood and then mixed between the blood and the tissue fluids by diffusion through the capillary walls.

In the extracellular fluid are the ions and nutrients needed by the cells to maintain cell life. Thus, all cells live, essentially in the same environment—the extracellular fluid. For this reason, the extracellular fluid is also called the *Internal environment* of the body, or the *milieu intérieur,* a term introduced more than 100 years ago by the great 19th-century French physiologist Claude Bernard.

The extracellular fluid contains large amounts of *sodium, chloride,* and *bicarbonate ions* plus nutrients for the cells, such as *oxygen, glucose, fatty acids,* and *amino acids.* It also contains *carbon dioxide* that is being transported from the cells to the lungs to be excreted, plus other cellular waste products that are being transported to the kidneys for excretion.

The intracellular fluid differs significantly from the extracellular fluid; specifically, it contains large amounts of *potassium, magnesium,* and *phosphate ions* instead of the sodium and chloride ions found in the extracellular fluid.

Body organ systems:

System	Major structure	General functions
Nervous system	**Divided into two subdivisions: 1-Central Nervous System (CNS) ,which include the brain and spinal cord.**	**1. Integration of body processes. 2. Control of voluntary effectors (skeletal muscles). 3. Control of involuntary effectors (smooth muscle, cardiac muscle, glands. 4. Response to stimuli.**

	2-Peripheral Nervous System (PNS) ,which include the cranial nerves arising from the brain and spinal nerves arising from the spinal cord.	**5. Responsible for conscious, thought and perception, emotions, personality, the mind.**
Muscular system	**There are three kinds of muscle:** **1. Skeletal muscle** **2. Cardiac muscle** **3. Smooth muscle**	**1. Muscles produce movement by acting on the bones of the skeleton, pumping blood, or propelling substances throughout hollow organ systems.** **2. Muscles aid in maintaining posture by adjusting the position of the body with respect to gravity.** **3. Muscles stabilize joints by exerting tension around the joint.** **4. Muscles generate heat as a function of their cellular metabolic processes.**
Circulatory system	**The circulatory system consists of two subdivisions:** **A/ *Cardiovascular system*: Consist of heart, blood vessels.** **B/ *Lymphatic system:* Include lymphatic vessels and lymphatic tissue (Spleen, Thymus, Tonsils and Lymph nodes).** **./**	**1- *Functions in respiration*/ by delivering oxygen (O_2) to the cells and removing carbon dioxide (CO_2) from them.** **2- *Functions in nutrition* /by carrying digested food substances to the cells of the body.** **3- *Functions in Excretion* through helping to dispose waste products and poisons that would harm the body if they accumulated. These substances include carbon dioxide, salts, and ammonia.** **4- *Functions in transportation*/All the substances essential for cellular metabolism are transported by circulatory system, which include respiratory, nutritive & excretory substances.** **5- *Functions in regulation*/ include : <u>Hormonal</u> regulation where the blood carry hormones from their site of origin to their target organs. , and <u>temperature</u> regulation which is aided by the diversion of blood from deeper to more superficial cutaneous vessels or vice versa.** **6- *Functions in defense (Immunity)* through protect against blood loss from injury and (by clotting mechanism) and against foreign microbes or toxins introduced in to the body (by the Leukocytes).**
Respiratory system	**The Upper Respiratory Tract** • **Nose (nostrils)** • **Pharynx** • **Larynx (voice box)** • **Trachea (windpipe)** **The Lower Respiratory Tract** • **Bronchi (bronchioles)** • **Alveoli (air sacs) - The sacs in the lungs where**	**1-Ventilate the lungs** **2-Extract oxygen from the air and transfer it to the blood stream** **3-Excrete carbon dioxide and water vapor** **4-Maintain the acid base of the blood**

	gas exchange occurs. • **Lungs - The two inverted-cone shaped organs present in the chest of human beings**	
Urinary system	**1. Kidneys** **2. Ureters** **3. Urinary bladder** **4. Urethra**	**A. *Filters Waste Products from Blood* / as ammonia and urea (amino acids break down), and uric acid (nucleic acids break down).** ***B. Regulates Ion Levels in the Plasma* /as (sodium, potassium, chloride and other ions) lost in the urine.** ***C. Regulates Blood pH* /by regulating the number of H^+ and bicarbonate ions (HCO^{3-}) lost in the urine.** ***D. Conserves Valuable Nutrients* /as (glucose, amino acids and other valuable nutrients).** ***E. Regulates Blood Volume* / by:** **1. Releasing renin, a hormone that after a series of reactions eventually restricts salt and water loss at the kidneys.** **2. Adjusting the volume of water lost in the urine** ***F. Regulates RBC Production* /the kidneys release erythropoietin, a hormone that stimulates the hemocytoblasts (stem cells in the bone marrow) to increase red blood cell formation.**
Digestive system	**1. Mouth** **2. Throut** **3. Esophagus** **4. Stomach** **5. Liver** **6. Pancreas** **7. Small intestine** **8. Large intestine**	**1-Extracts and absorb nutrients from food** **2-Removes wastes** **3-Maintains water** **4-Chemical balance**
Immune system	**White blood cells, lymph nodes, skin**	**Defend against pathogens and disease**
Endocrine system	**Hypothalamus , pituitary gland, thyroid gland , adrenal gland , pancreas ,testis and ovary**	**1-Regulate body temperature, Metabolism, Development and Reproduction** **5-Mantain hemostasis** **6-Regulate other organ system**
Integumentary system	**Skin, nails, hair**	**1-Protect against injury, infection , and fluid loss** **2-Help regulate body temperature**
Reproductive system	**Testes, penis in male** **Ovary , uterus , breasts in female**	**Produce gametes and offspring**
Skeletal system	**Bones and Joints**	**1- Protects and supports the body and organs** **2- Interacts with skeletal muscles** **3- Produces red blood cells, white blood cells , and platelets**

Homeostasis

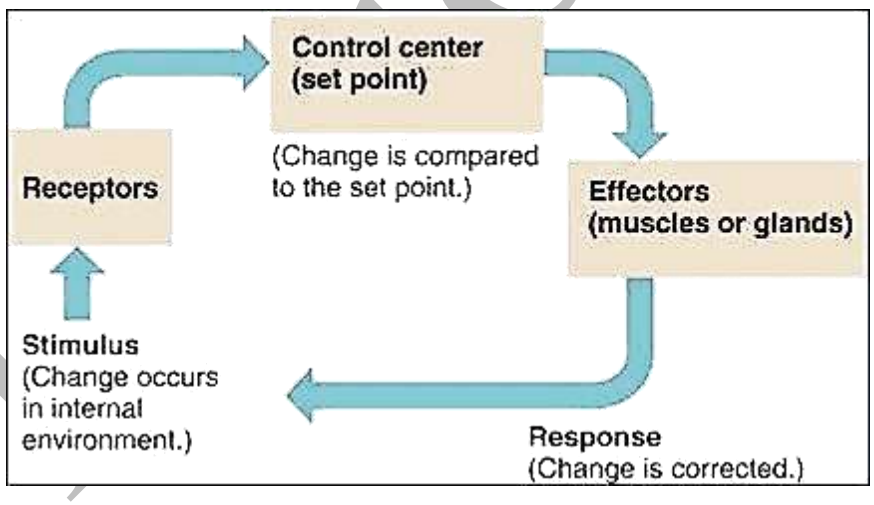
Homeostasis in a general sense refers to stability, balance or equilibrium. Maintaining a stable internal environment requires constant monitoring and adjustments as conditions change. This adjusting of physiological systems within the body is called homeostatic regulation.

Human homeostasis refers to the body's ability to physiologically regulate its inner environment to ensure its stability in response to fluctuations in the outside environment and the weather.

Homeostasis and Feedback

Feedback helps maintain homeostasis in a chain of cause and effect that forms a circuit or loop. The body maintains homeostasis through a number of self-regulating control systems, or homeostatic mechanisms. These mechanisms share the following three components:

1. **Receptors,** which provide information about specific conditions (stimuli) in the internal environment.
2. **A control center**, which includes a set point, tells what a particular value should be (such as body temperature at 98.6°F).
3**. Effectors**, such as muscles or glands, which elicit responses that alter conditions in the internal environment.



Our bodies control body temperature in a similar way. The brain is the control center, the receptor is our body's temperature sensors, and the effector is our blood vessels and sweat glands in our skin. When we feel heat, the temperature sensors in our skin send the message to our brain. Our brain then sends the message to the sweat glands to increase sweating and increase blood flow to our skin. When we feel cold, the opposite happens. Our brain sends a message to our sweat glands to decrease sweating, decrease blood flow, and begin shivering. This is an ongoing process that continually works to restore and maintain homeostasis.

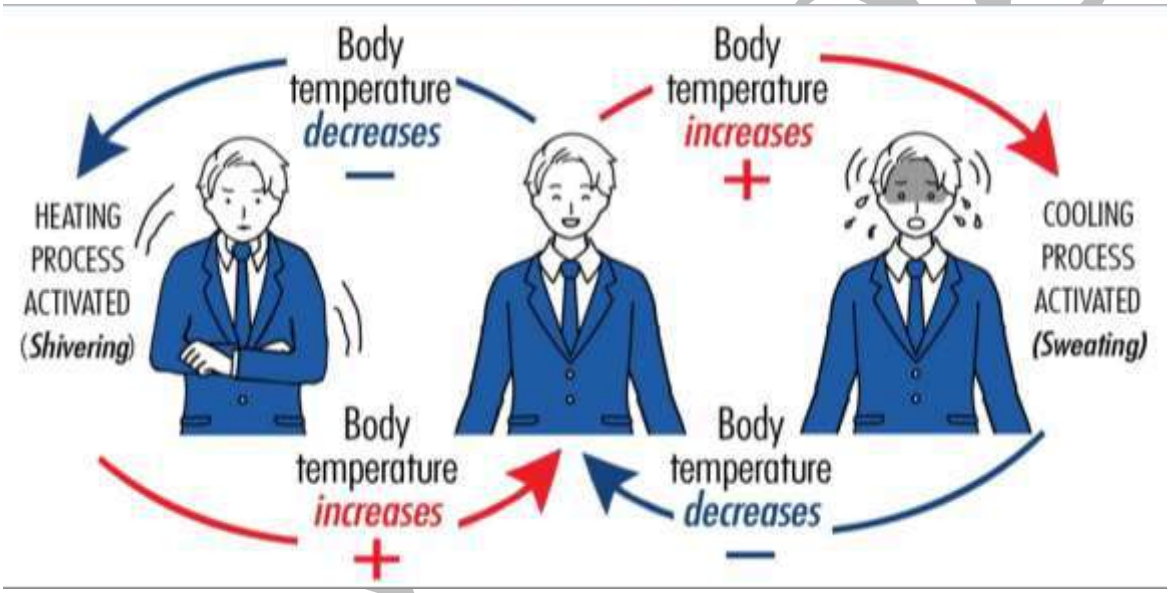
Homeostasis Mechanisms:

When a change of variable occurs, there are two main types of feedback to which the system reacts:

A. **Negative feedback**: a reaction in which the system responds in such a way as to reverse the direction of change. Since this tends to keep things constant, it allows the maintenance of homeostasis. Examples:

- When the concentration of carbon dioxide in the human body increases, the lungs are signaled to increase their activity and expel more carbon dioxide.

- Thermoregulation is another example of negative feedback. When body temperature rises, receptors in the skin and the hypothalamus sense a change, triggering a command from the brain. This command, in turn, affects the correct response, in this case a decrease in body temperature.



- Blood glucose: is regulated with two hormones, **Insulin** and **Glucagon**, both released from the pancreas. When blood sugar levels become too high, insulin is released from the pancreas. Glucose is stored in body cells as glycogen, lowering the blood sugar levels. On the other hand, when blood sugar levels become too low, glucagon is released. It promotes the release of glycogen, converted back into glucose. This increases blood sugar levels. If the pancreas is for any reason unable to produce enough of these two hormones, ***Diabetes*** results.
- Calcium: When blood calcium becomes too low, calcium-sensing receptors in the parathyroid gland become activated. This results in the release of Parathyroid hormone (PTH), which acts to increase blood calcium, e.g. by release from bones (increasing the activity of bone-degrading cells called osteoclasts). This hormone also causes calcium to be reabsorbed from urine and the GI tract. Calcitonin, released from the C cells in the thyroid gland, works the opposite way, decreasing calcium levels in the blood by causing more calcium to be fixed in bone.

B. **Positive feedback**: a response is to amplify the change in the variable. This has a destabilizing effect, so does not result in homeostasis. Positive feedback is less common in naturally occurring systems than negative feedback, but it has its applications. For example:
    - In nerves, a threshold electric potential triggers the generation of a much larger action potential.
    - Blood clotting
    - Events in childbirth are other types of positive feedback.

Lecture 2 /---------- Nervous system (part 1)

The nervous system is **histologically** composed of **neurons** which produce and contact electrochemical impulses and **supporting cells,** which assist the functions of neurons.

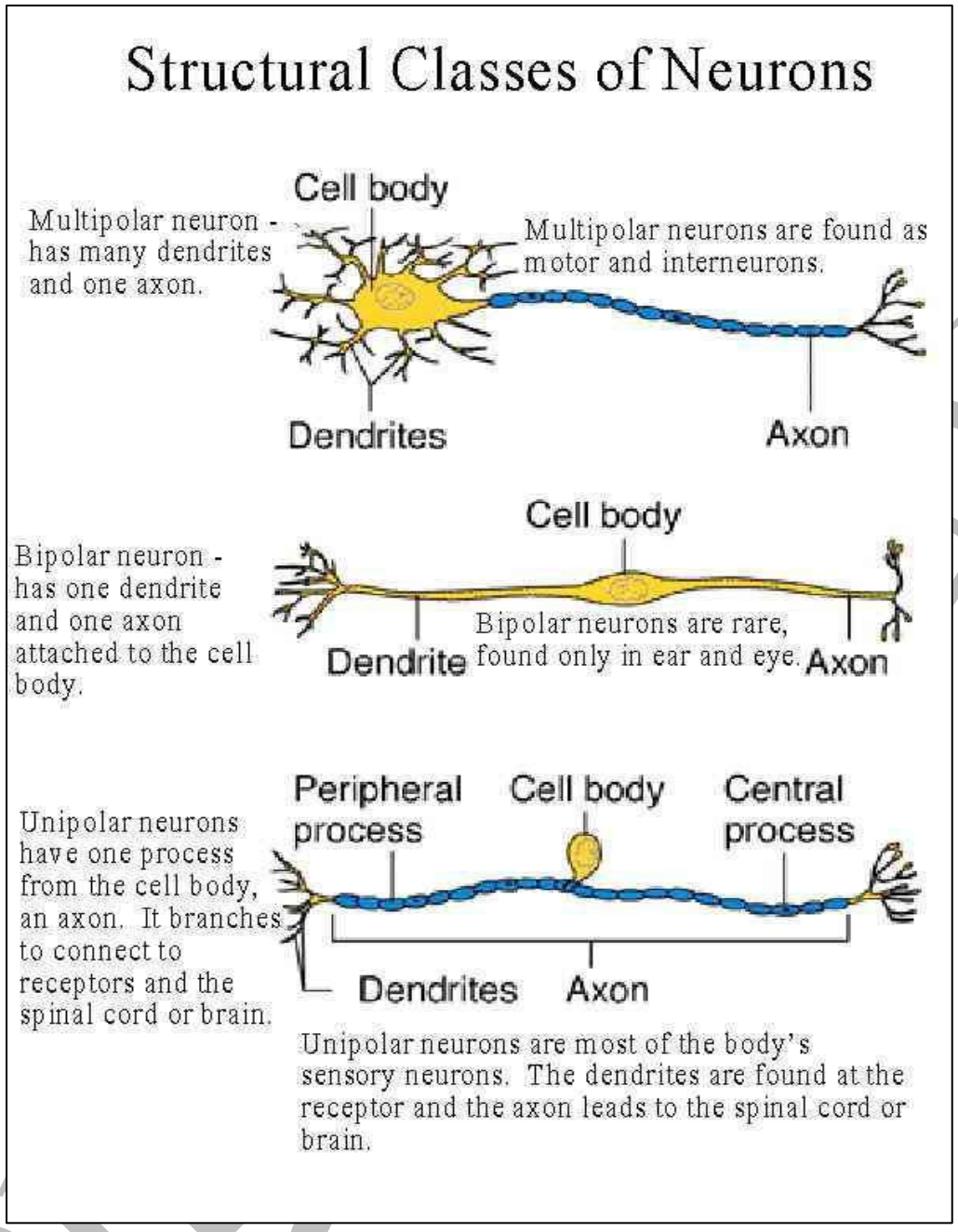
Neurons – are the basic structural and functional units of the nervous system. They are specialized to respond to physical and chemical stimuli, conduct impulses and release chemical regulators.

Neuron Structure:

In order to connect to other cells, receptors, and effectors, neurons have **cytoplasmic extensions** which attach to an enlarged area known as the **cell body** or **Cyton**. Within the cell body are the nucleus and the neuron's biosynthetic machinery, the rough endoplasmic reticulum and the Golgi bodies. These organelles are so highly concentrated they can be visualized with a light microscope when stained with a specific technique called **Nissl bodies**, they manufacture the **Neurotransmitters**., which transported to the axon terminus by ***microfilaments and microtubules***. There are two basic types of cytoplasmic extensions: the **dendrites** and the **axon**. Dendrites are short branching processes which receive stimuli from receptors or other neurons.

Types of neurons based on structure:

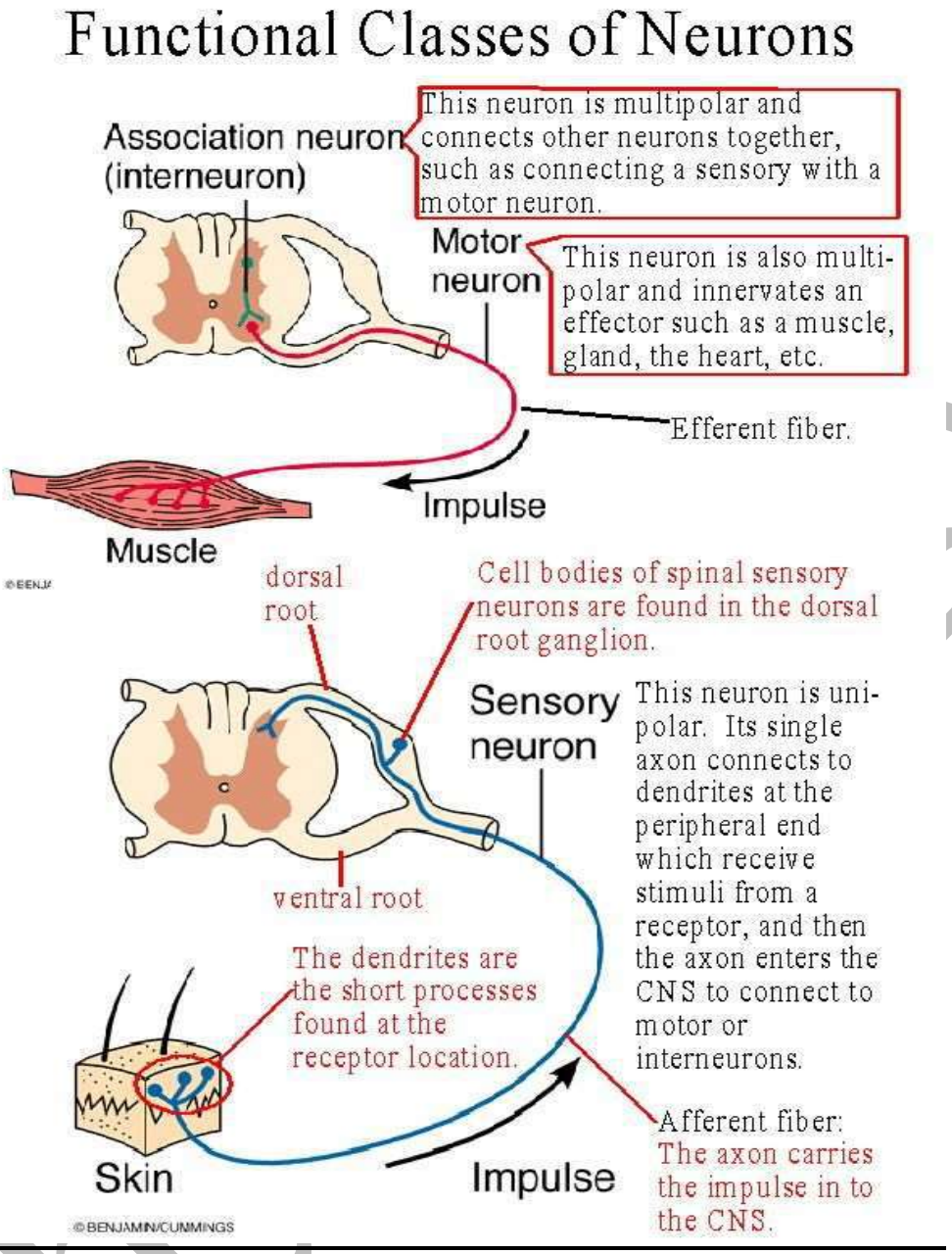
1. **Multipolar neuron:** have many poles or processes, the dendrites and the axon. Multipolar neurons are found as *Motor neurons* and *Inter neurons*.
2. **Bipolar neurons** with two processes, a dendrite and an axon.
3. **Unipolar neurons**, which have only one process, classified as an axon. Found as *sensory neurons*. The axon carries the action potential to the central nervous system.



<u>Types of neurons based on function:</u> (based on the direction which they conduct impulses)

1. **Motor neurons** - these carry a message to a muscle, gland, or other effectors. They are said to be ***efferent***, i.e. they carry the message *away* from the central nervous system. Include 2 types (<u>Somatic neurons</u> and <u>Autonomic neurons</u> , which include (sympathetic and parasympathetic neurons).
2. **Sensory neurons** - these carry a message in to the CNS. They are ***afferent***, i.e. going toward the brain or spinal cord.
3. **Interneuron** (association neuron, connecting neuron) - these neurons connect one neuron with another. For example, in many reflexes interneurons connect the sensory neurons with the motor neurons.

- The three functional types of neurons together composed the ***Reflex arc***.



Supporting cells:

1. **Schwann cells** - produce the myelin sheath in the PNS. The myelin sheath protects and insulates axons, maintains their micro-environment, and enables them to regenerate and re-establish connection with receptors or effectors.
2. **Oligodendrocyte**- produces the myelin sheath in the CNS which insulates and protects axons**.**
3. **Satellite cells**- surround cell bodies of neurons in ganglia. Their role is to maintain the micro-environment and provide insulation for the ganglion cells.
4. **Microglia** - these cells are phagocytic to defend against pathogens. They may also monitor the condition of neurons.
5. **Astrocytes**- these cells anchor neurons to blood vessels, regulate the micro-environment of neurons in CNS, and regulate transport of nutrients and wastes to and from neurons.

6. **Ependymal** cells - these cells line the fluid-filled cavities of the brain and spinal cord. They play a role in production, transport, and circulation of the cerebrospinal fluid.

Myelin: is an insulating layering that forms around nerves, including those in the brain and spinal cord. It is made up of protein and fatty substances. The purpose of the myelin sheath is to allow rapid and efficient transmission of impulses along the nerve cells. If the myelin is damaged, the impulses slow down. This can cause diseases like multiple sclerosis.

Lecture 3/----------Nervous system (part 1)

Impulses formation:

Impulse: Electrical (Charge exchange on each side of the axon membrane), Physical (Change in membrane permeability) and chemical changes (energy production and release). It is simply the movement of action potentials along a nerve cell.

All cells in the body maintain differences (Voltage) across the membrane, or (**resting membrane potential)** , in which the inside of the cell is negatively charged in comparison to the outside of the cell , in neurons it is equal to -70 mv , in muscle it is equal to – 85 mv.

In resting potential, the cell membrane is High permeability to K^+ , Less permeability to Cl^- and Na^+ and the presence of organic big negatively charged molecules (Proteins) inside the axon, makes the inside negatively charged and the outside positively charged.

After stimulation, the membrane become in action potential and said to be (depolarized) , the membrane become High permeability to Na_+ , Less permeability to $K^{+.}$

Action potential are localized (only affect a small area of nerve cell membrane). So, when one occurs, only a small area of membrane depolarizes. As a result, for a split second, areas of membrane adjacent to each other has opposite charges (***The depolarized membrane is negative on the outside and positive on the inside***). An electrical circuit or ***mini-circuit*** develops between these oppositely charged areas). The mini-circuit stimulates the adjacent area and, therefore, an action potential occurs. This process repeats itself and action potentials move down the nerve cell membrane.

Action potential is a very rapid change in membrane potential that occurs when a nerve cell membrane is stimulated. Specifically, the membrane potential goes from the resting potential (typically -70 mV) to some positive value (typically about +35mV) in a very short period of time (just a few milliseconds).

Action potential occurs only when the membrane is stimulated (depolarized) enough so that sodium channels open completely. The minimum stimulus needed to achieve an action potential is called the ***threshold stimulus***.

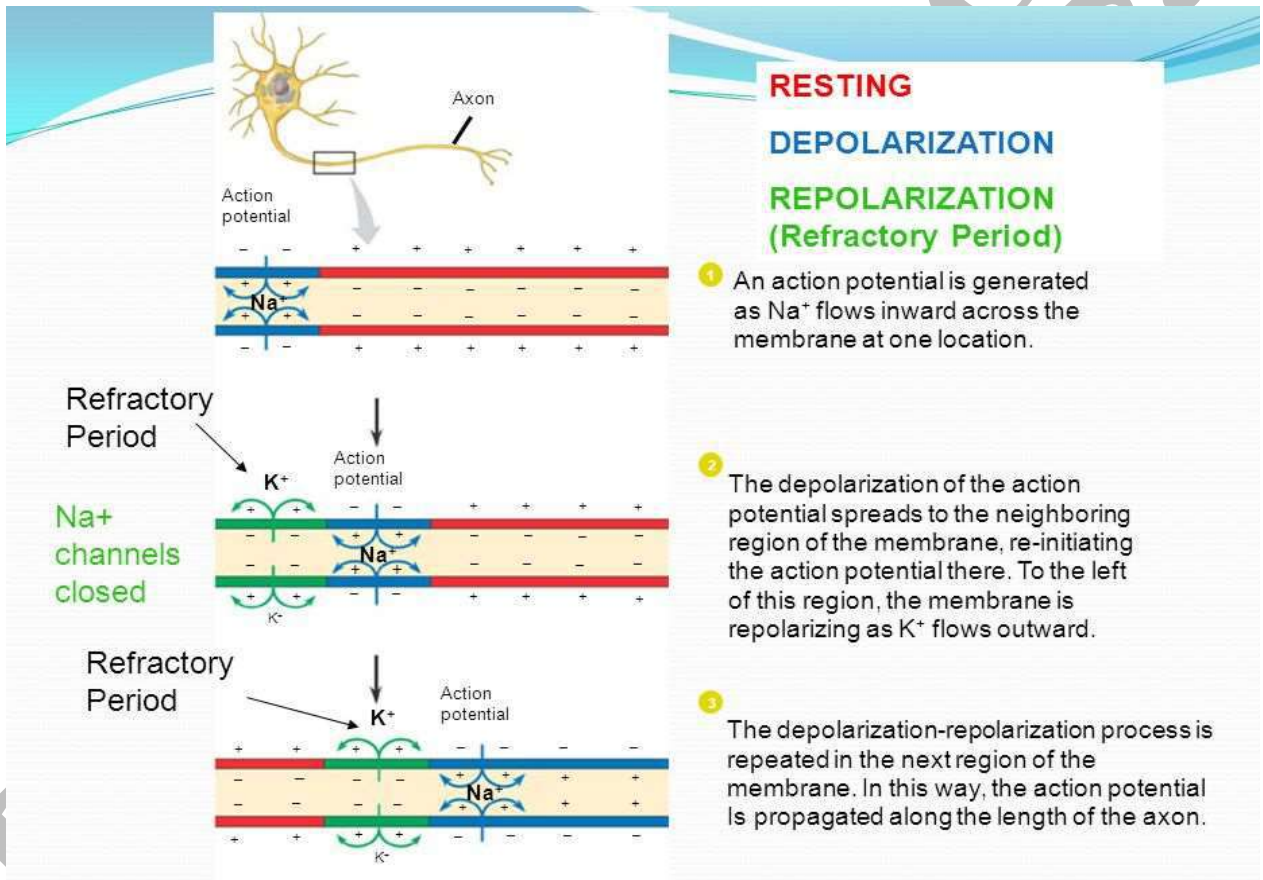
The length of time that the Na^+ and K^+ channels stay open is independent of the strength of the depolarization stimulus. The amplitude (size) of action potentials is therefore ***all or none.***

Polarization ..... Depolarization .....Repolarization

Resting potential Action potential

The permeability of the axon membrane to Na^+ and K^+ is regulated by gates, which open in response to stimulation. Net diffusion of these ions occurs in two stages: first Na^+ moves into the axon. Then K^+ moves out. This flow of ions, and the changes in the membrane potential that result, constitute an event called an **action potential.**

The action of Na^+ /K^+ pumps , help to maintain a potential differences because , they pump out 3 Na^+ for every 2 K^+ into the cell . As a result the Na^+ became at high concentration in extracellular fluid than inside the cell and K^+ at high concentration within the cell. The physiologic ability of neurons and muscle cells to produce and conduct changes in membrane potential known as **excitability** or **irritability.**



When the axon membrane has been depolarized to threshold level, the Na^+ gates open and the membrane becomes permeable to Na^+. Since the gates for the Na^+ channels of the axon membrane are voltage- regulated, this additional depolarization opens more Na^+ channels and makes the membrane even more permeable to Na^+. As a result, more Na^+ can enter the cell and indices a depolarization that opens even more voltage - regulated Na^+ gates.

Since the myelin sheath prevents inward Na^+ current. Action potential can be produced only at gaps in the myelin sheath called the node of Ranvier. This leaping of the action potential from node to node is known as ***Saltatory conduction.***

Other types of action potential in the human body:

1. ***Cardiac action potential***: plays an important role in coordinating the contraction of the heart. The cardiac cells of the sinoatrial node (SA node) provide the pacemaker potential that synchronizes the heart.
2. ***Muscular action potential***: the action potential in a normal skeletal muscle cell is similar to the action potential in neurons. Action potential result from the depolarization of the cell membrane (the sarcolemma), which opens voltage – sensitive sodium channels; these became inactivated and the membrane is repolarized through the outward current of potassium ions.

❖ **Refractory period:**

During the time that a patch of axon membrane is producing an action potential, it is incapable of responding – or refractory – to further stimulation. If a second stimulus is applied during the time that an action potential is being produced, the second stimulus will have no effect on the axon membrane. The membrane is thus said to be in a refractory period; it cannot respond to any subsequent stimulus.

❖ **Cable properties of neurons:**

The term cable properties refer to the ability of a neuron to transmit changes through its cytoplasm. These cable properties are quite poor because there is a high internal resistance to the spread of changes and because many charges leak out of the axon through its membrane.

❖ **Synapses:**

Is the functional connection between a neuron and a second cell? In CNS, this other cell is also a neuron. In PNS, this other cell may be a neuron or an effectors cell (gland or muscle).

Synaptic Transmission: is the process whereby one neuron communicates with other **neurons** or **effectors,** such as a muscle cell. A typical neuron has a cell body; branching processes specialized to receive incoming signals (dendrites), and a single process (axon) that carries electrical signals away from the neuron toward other neurons or effectors.

Electrical signals carried by **axons** are **action potentials.** Axons often have thousands of terminal branches, each ending as a bulbous enlargement, the ***Synaptic knob or Synaptic terminal***. At the synaptic knob, the action potential is converted into a chemical message which, in turn, interacts with the recipient neuron or effectors.

Synapses are junctional complexes between presynaptic membranes (*synaptic knobs*) and postsynaptic membranes (*receptor surfaces of recipient neurons or effectors*). The gap between them known as Synaptic cleft. Synaptic knobs contain many membrane-bounded synaptic **vesicles,** 40 to 100 **nanometers** in diameter, contain the **Neurotransmitter.** Synaptic knobs also contain mitochondria, microtubules, and other organelles.

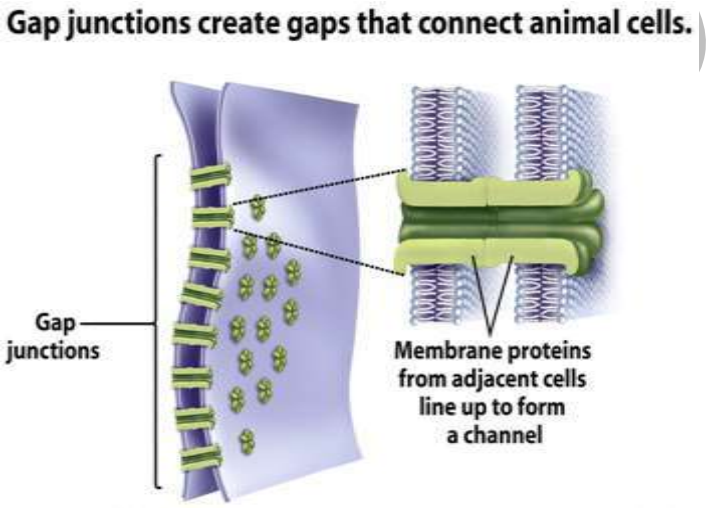
In brief, the impulses transmit from cell to another by 2 ways:

1. **Electrical synapses (Gap junctions)**
2. **Chemical synapses (Neurotransmitters)**

Electrical Synapses (Gap junctions)

Gap junctions are a specialized intercellular connection between multitudes of animal cell-types. They directly connect the cytoplasm of two cells, which allows various molecules, ions and electrical impulses to directly pass through a regulated gate between cells. One gap junction channel is composed of two connexons (or hemichannels), which connect across the intercellular space. Properties include:

1. The presynaptic and postsynaptic membranes are partially fused. This allows the action potential to cross from the membrane of one neuron to the next without the intervention of a neurotransmitter.
2. Electrical synapses often lack the directional specificity of chemical synapses and may transmit a signal in either direction.
3. Gap junctions present in cardiac muscle, some smooth muscles, between glial cells and various regions in the brain. It is also present in embryonic tissue, but disappears as the tissue became more specialized.



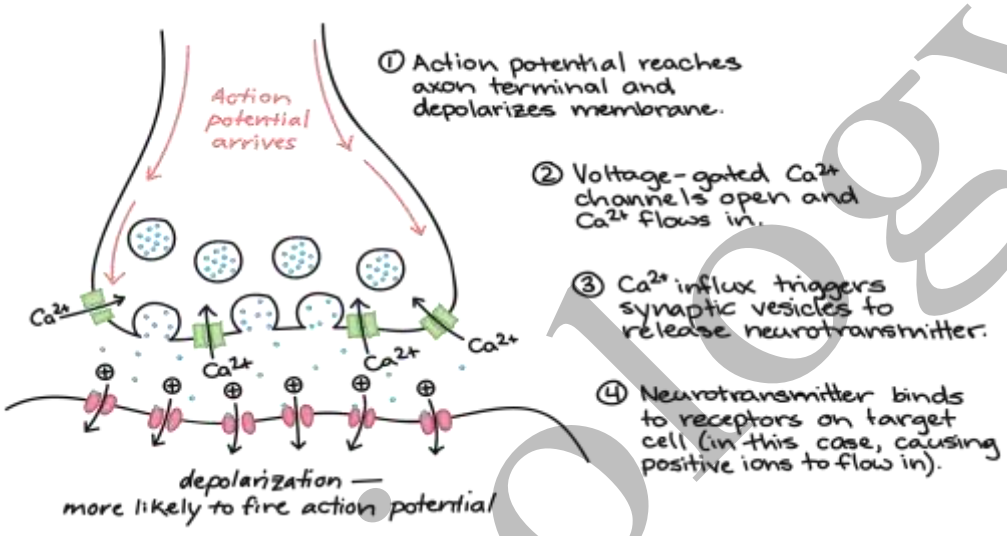
Chemical synapses (Neurotransmitters)

Neurotransmitter include: Acetylcholine, Monoamines, Serotonin, Dopamine, and Norepinephrine, others (Amino acids, polypeptides and Nitric oxide).

Action potentials arriving at synaptic knobs trigger the release of neurotransmitter into the **synaptic cleft**. Action potentials open calcium channels in the membrane of the **synaptic knob**, which causes an inward movement of calcium **ions**. Calcium ions trigger the release of neurotransmitter from synaptic vesicles into the synaptic cleft. The synaptic vesicles fuse with the presynaptic membrane during this process of **exocytosis**. The membranes of old vesicles become part of the presynaptic membrane and new vesicles pinch off from an

adjacent area of membrane. These new vesicles are subsequently refilled with newly synthesized or "recycled".

Once released into the synaptic cleft, neurotransmitters remain active until they are either altered chemically or taken back into the synaptic knob by special carrier systems and recycled. At cholinergic synapses, ***Acetylcholinesterase*** is present in the synaptic cleft. This **enzyme** cleaves the neurotransmitter into acetate and choline, neither of which is active. Serotonin and epinephrine, on the other hand, are taken up into the presynaptic terminal and recycled.

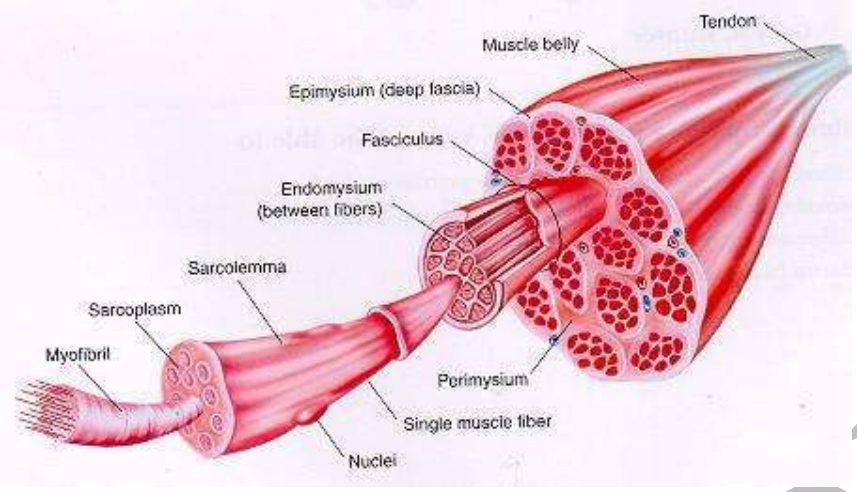


Lecture 4 / ----------Muscular system

The 3 types of muscle tissue are cardiac, smooth, and skeletal.

1- Skeletal muscle

Each skeletal muscle fiber is a single cylindrical muscle cell. An individual skeletal muscle may be made up of thousands of muscle fibers bundled together and wrapped in a connective tissue covering. Each muscle is surrounded by a connective tissue sheath called the ***Epimysium***.. Portions of the epimysium project inward to divide the muscle into compartments. Each compartment contains a bundle of muscle fibers. Each bundle of muscle fiber is called a ***Fasciculu***s and is surrounded by a layer of connective tissue called the ***Perimysium.*** Within the fasciculus, each individual muscle cell, called a muscle fiber, is surrounded by connective tissue called the ***Endomysium*** (see in figure 1). Skeletal muscle cells are multinucleated from the fusion of muscle cells.



2- Cardiac muscle

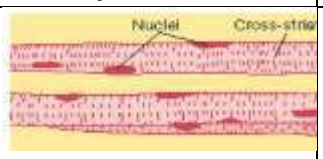
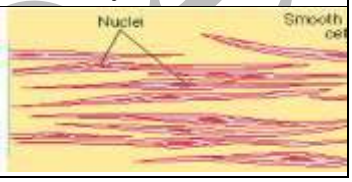
Cardiac muscle is a type of involuntary mononucleated, striated muscle found exclusively within the heart. Its function is to "pump" blood through the circulatory system by contracting. Unlike skeletal muscle, which contracts in response to nerve stimulation, and like smooth muscle, cardiac muscle is myogenic, meaning that it stimulates its own contraction without a requisite electrical impulse coming from the central nervous system. A single cardiac muscle cell, if left without input, will contract rhythmically at a steady rate. This transmission of impulses makes cardiac muscle tissue similar to nerve tissue, although the cells are connected by ***Intercalated discs***, which conduct electrical potentials directly, rather than the chemical synapses used by neurons.

3- Smooth muscle

Smooth muscle is a type of non-striated muscle, found within the "walls" of hollow organs; such as the bladder, the uterus, and the gastrointestinal tract, and also lines the lumen of the body, such as blood vessels. Smooth muscle is fundamentally different from skeletal muscle and cardiac muscle in terms of structure and function. Smooth muscle is spindle shaped, and like any muscle, can contract and relax. In order to do this it contains intracellular contractile proteins called actin and myosin. While the fibers are essentially the same in smooth muscle as they are in skeletal and cardiac muscle, the way they are arranged is different. As non-striated muscle, the actin and myosin is not arranged into distinct sarcomeres that form orderly bands throughout the muscle cell. The cells themselves are generally arranged in sheets or bundles and connected by gap junctions. In relaxed state, each cell is spindle-shaped, 25-50 μm long and 5 μm wide. The cells that compose smooth muscle have single nuclei.

Table. Comparison of Muscle Types

Characteristic	Muscle Type		
	Skeletal	**Cardiac**	**Smooth**
Nuclei	Multinucleated; peripherally located	Single nucleus; centrally located	Single nucleus; centrally located
Banding	Actin and myosin form distinctive bands	Actin and myosin form a distinctive bands	Actin and myosin , NO distinctive bands

Z disks	Present	Present	Z disks not present; cytoplasmic dense bodies are present
T tubules	T tubules at A- junction; triads present	T tubules at Z disk; diads present	No T tubules; no triads or diads
Cellular junctions	No junctional complexes	Intercalated disks	Gap junctions
Neuromuscular junctions	Present	Not present; contraction is intrinsic	Not present; contraction is intrinsic, neural, or hormonal
An aerobic capacity	High	Low	Low
Striation	Striated	Striated	Not Striated
Electrical activity origin	Neurogenic	Myogenic	Neurogenic/Myogenic
Presence	Leg, Arm	Heart	Arterioles, Got
	Voluntary	Involuntary	Involuntary
			

Muscle structure

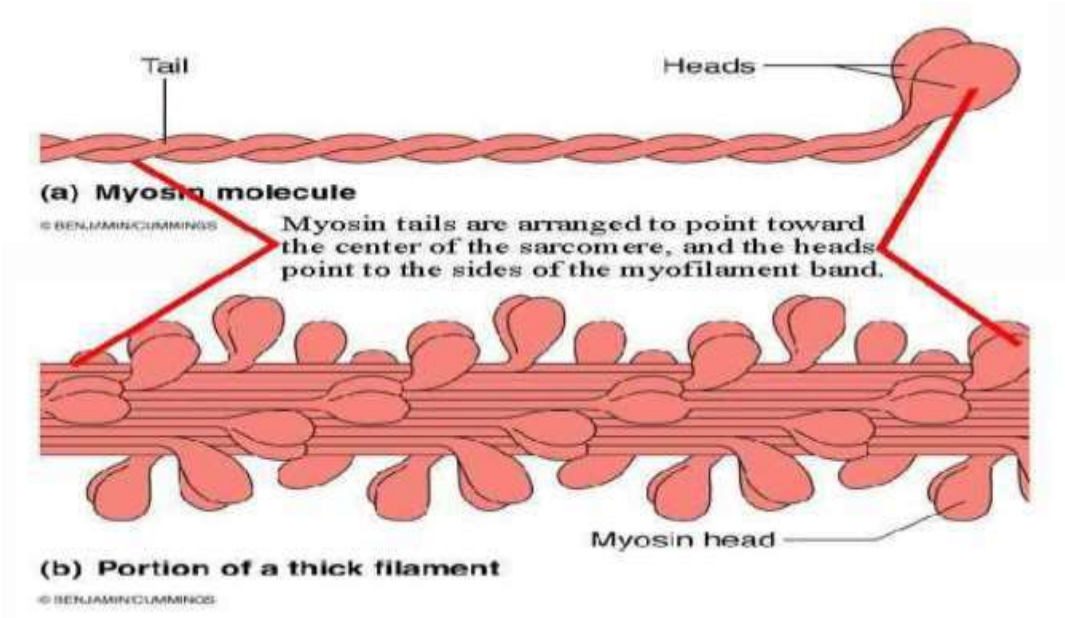
Looking at muscle anatomy shows that each muscle is made up of ***Muscle cells or*** **(Myofibers).** The functional characteristics of a skeletal muscle cell:

- Each muscle cell (myofibers) is organized into sections along its length. Each section is called a ***Sarcomere*** and they are repeated right along the length of a muscle fiber. The sarcomere is the smallest contractile portion of a muscle fiber.

- The cell membrane is called the ***Sarcolemma****, which* is structured to receive and conduct stimuli.
- *The* ***Sarcoplasm*** of the cell is filled with contractile ***Myofibrils or Myofilaments*** and this result in the nuclei and other organelles being relegated to the edge of the cell. Sarcoplasm contains glycogen, fat particles, enzymes and the mitochondria.

- Muscle fibers **(Myofibers)** are grouped into bundles (of up to 150 fibers) called ***Fasciculi.***
- Myofibrils *or Myofilaments* are contractile units within the cell which consist of a regular array of protein **myofilaments**.
- There are two types of protein filaments ***Actin*** and ***Myosin****,* which is run in parallel to each other along the length of the muscle fiber.
- **Myosin (1):** is made of multiple molecules of a protein called **Myosin.** Each myosin molecule is composed of two parts: the globular "head" and the elongated "tail". They are arranged to form the **thick filaments**. The tiny globular heads protrude from

the filament at regular intervals. These are called **Cross bridges** and play a pivotal role in muscle action.



- **Actin (2):** is made of multiple molecules of a protein called **Actin**, which is composed of globular proteins (G actin units) arranged to form a double coil (double alpha helix) to form the **thin filament.**

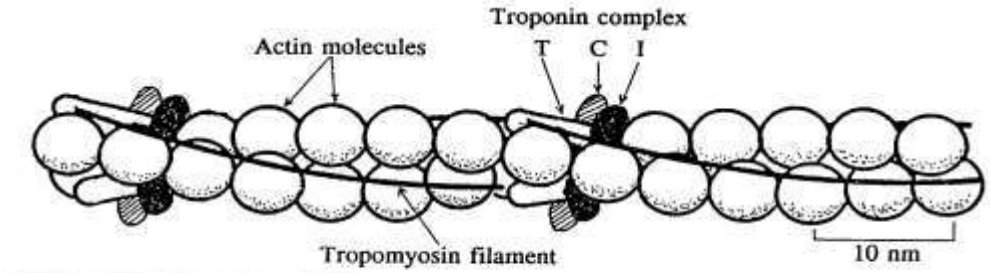


Figure 11.9 Schematic drawing of part of an actin filament showing the relationship between successive pairs of actin molecules, thin filaments of tropomyosin, and the three types of troponin. Another depiction of a (nonmuscle) actin filament is given in Figure 2.4A.

- Each thin myofilament is wrapped by a **tropomyosin (3)** protein, which in turn is connected to the **troponin (4)** complex.
- The sarcomere is often divided up into different zones to show how it behaves during muscle action. The **Z-line** separates each sarcomere. The **H-zone** is the center of the sarcomere and the **M-line** is where adjacent myosin filaments anchor on to each other.
- The arrangement of the thick myosin filaments across the myofibrils and the cell causes them to refract light and produce a dark band known as the **A Band**. In between the A bands are a light area where there are no thick myofilaments, only thin actin filaments. These are called the **I Bands**. The dark bands are the **striations** seen with the light microscope.

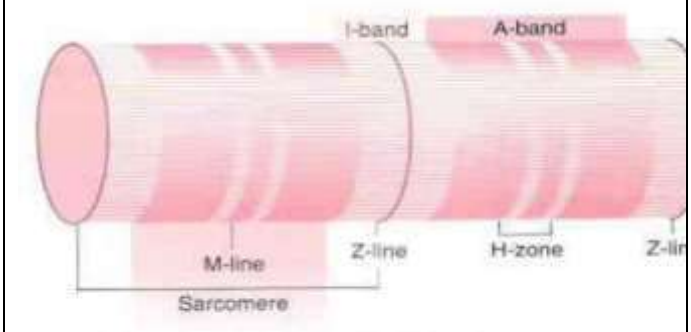


Figure 2: Myofibril divided into 2 sarcomeres

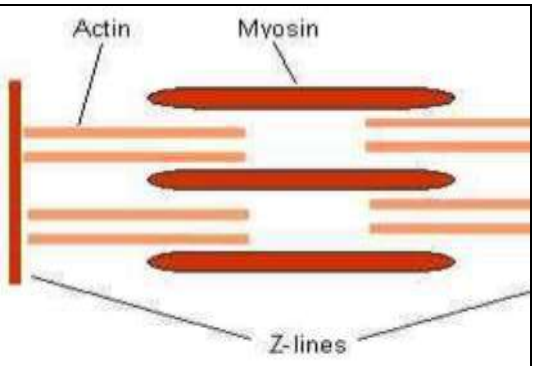


Figure 3: Arrangement of actin and myosi filaments in a single sarcomere

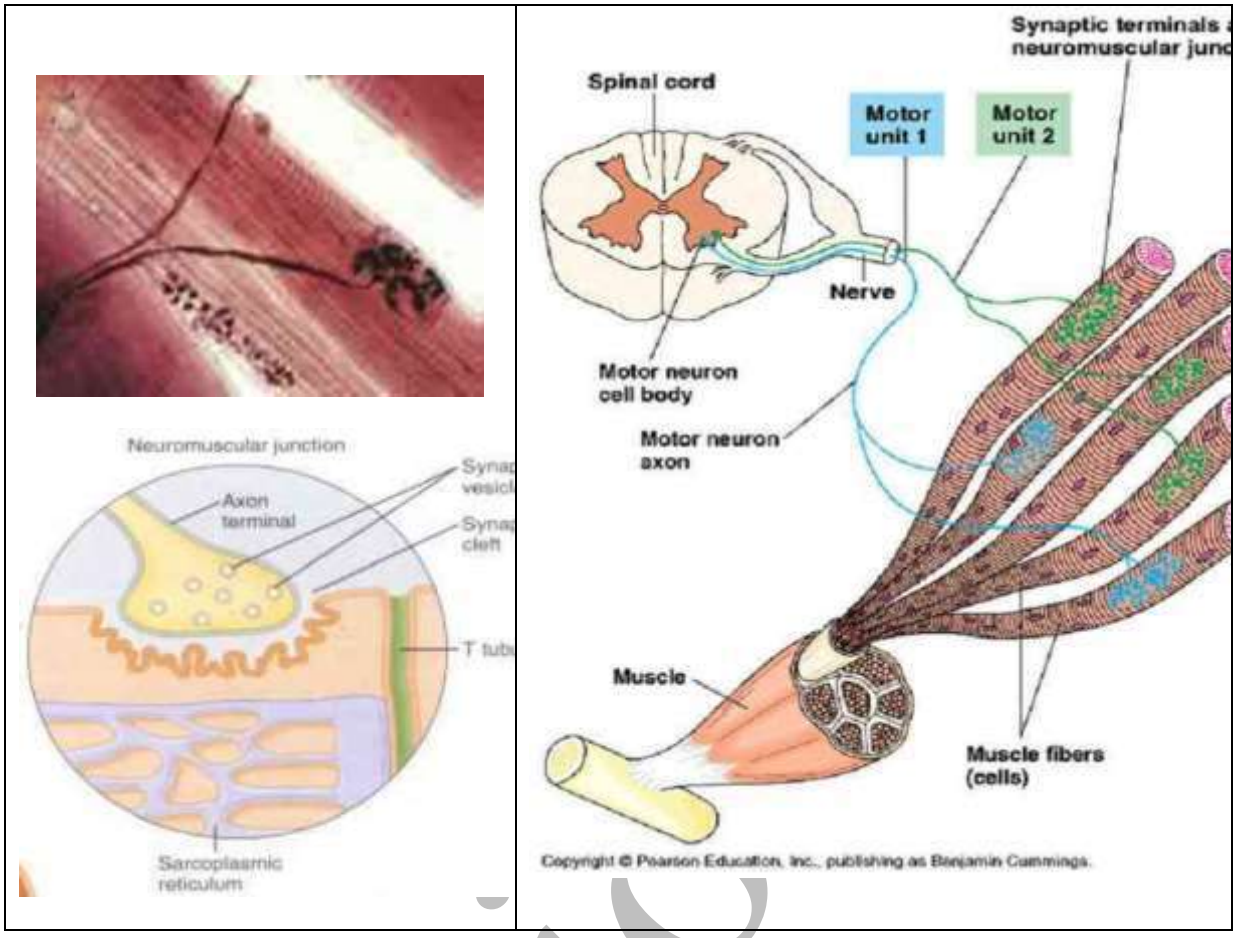
- As the sarcomeres contract the myofibrils contract. As the myofibrils contract the muscle cell contracts. And as the cells contract the entire muscle contracts.
- **Terminal cisternae:** An expanded portion of the sarcoplasmic reticulum in which Ca^{+2} ions is stored during relaxation of the muscle.
- **Transverse tubules**: (or T-tubule) is a deep invagination of the sarcolemma, which is the plasma membrane of skeletal muscle and cardiac muscle cells. These invaginations allow depolarization of the membrane to quickly penetrate to the interior of the cell

Motor Units

All motor neurons leading to skeletal muscles have branching axons, each of which terminates in a neuromuscular junction with a single muscle fiber. Nerve impulses passing down a single motor neuron will thus trigger contraction in all the muscle fibers at which the branches of that neuron terminate. This minimum unit of contraction is called the **motor unit**.

Although the response of a motor unit is all-or-none, the strength of the response of the entire muscle is determined by the **number of motor units** activated. Each muscle cell is stimulated by a motor neuron axon. The point where the axon terminus contacts the sarcolemma is at a synapse called the **neuromuscular junction**. The terminus of the axon at the sarcolemma is called the **motor end plate.**

Motor end plate: The specialized region of the sarcolemma of the muscle fiber at the neuromuscular junction, that surrounding the terminal end of axon. The neuromuscular junction is the synapse between the nerve fiber and muscle fiber.

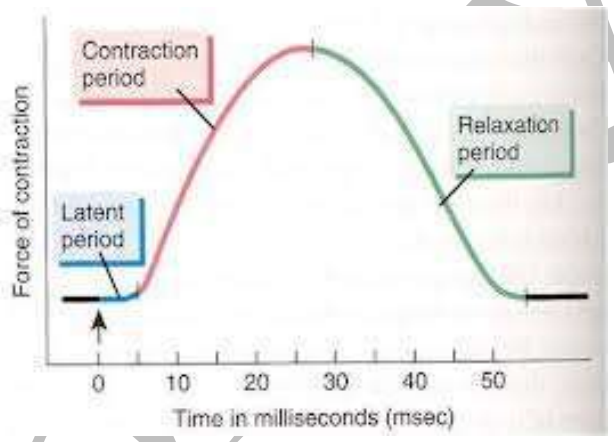


Mechanism of Muscle Contraction

1. The axons of the nerve cells of the spinal cord branch and attach to each muscle fiber forming a neuromuscular junction.
2. An action potential passes down the nerve.
3. The nerve releases Ca^{++} that results in the release of Acetylcholine (ACh).
4. ACh binds with receptors and opens Na^{+} channels (Na^{+} Channels open and Na^{+} in). There is a decrease in the resting potential.
5. Na^{+} rushes in and the sarcolemma depolarizes.
6. The positive patch in the membrane changes the adjacent patch of the membrane. Thus depolarization spreads.
7. Immediately after the action potential passes the membrane permeability changes again. Na^{+} channels close and K^{+} channels open. K^{+} rushes out of the cell. Cell reploraizes
8. Ca^{++} is stored in the sarcoplasmic reticulum. Depolarization releases the Ca^{++}.The Ca^{++} clears the actin binding sites.
9. During muscle contraction the thin actin filaments slide over the thick myosin filament. When Calcium is present the blocked active site of the actin clears.
10. Myosin head attaches to actin. (High energy ADP + P configuration).
11. Power stroke: myosin head pivots pulling the actin filament toward the center.
12. The cross bridge detaches when a new ATP binds with the myosin.

13. The end result is a shortening of the sarcomere. The distance between the Z discs shortens The H zone disappears, the dark A band increases because the actin & the myosin overlap more the light I band shortens.
14. Ca^{++} is removed from the cytoplasm. Tropomysin blocks the actin site.

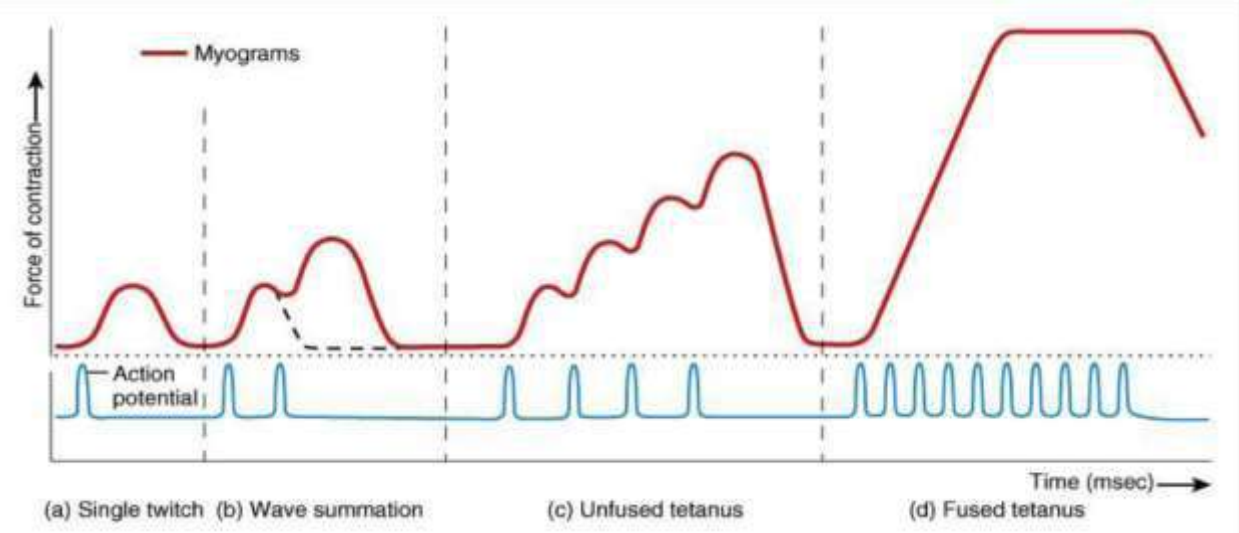
Muscle twitch:



A **Myogram** can record a twitch. There is a brief delay between the stimulation and the beginning of contraction, called the **latent period**. It corresponds to the change in Na^{+} and Ca^{++} ions occurring in the cell. In the second phase, the **contraction phase**, the muscle contracts. Myosin heads bind to actin and slide along it. It lasts 10-100 msec. The third phase or **relaxation period** lasts slightly longer than the contraction period. It corresponds to the calcium ions being shipped back into the sarcoplasmic reticulum. Shortly after initial stimulation, the muscle fiber cannot contract. It is the **refractory period**, lasting a short time in this muscle and is due to the depolarized state of the muscle membrane.

The process of contracting takes some 50 msec; relaxation of the fiber takes another 50–100 msec. Because the refractory period is so much shorter than the time needed for contraction and relaxation, the fiber can be maintained in the contracted state so long as it is stimulated frequently enough (e.g., 50 stimuli per second). Such sustained contraction is called ***Tetanus***.

In the figure, · When shocks are given at 1/sec, the muscle responds with a single twitch.· At 5/sec and 10/sec, the individual twitches begin to fuse together, a phenomenon called ***Clonus*** or ***Summation.*** · At 50 shocks per second, the muscle goes into the smooth, sustained contraction of tetanus.



Muscle fatigue: is a Physiological Inability of a muscle to contract. Muscle fatigue is a result of a relative depletion of ATP. When ATP is absent, a state of continuous contraction occurs. This causes severe muscle cramps.

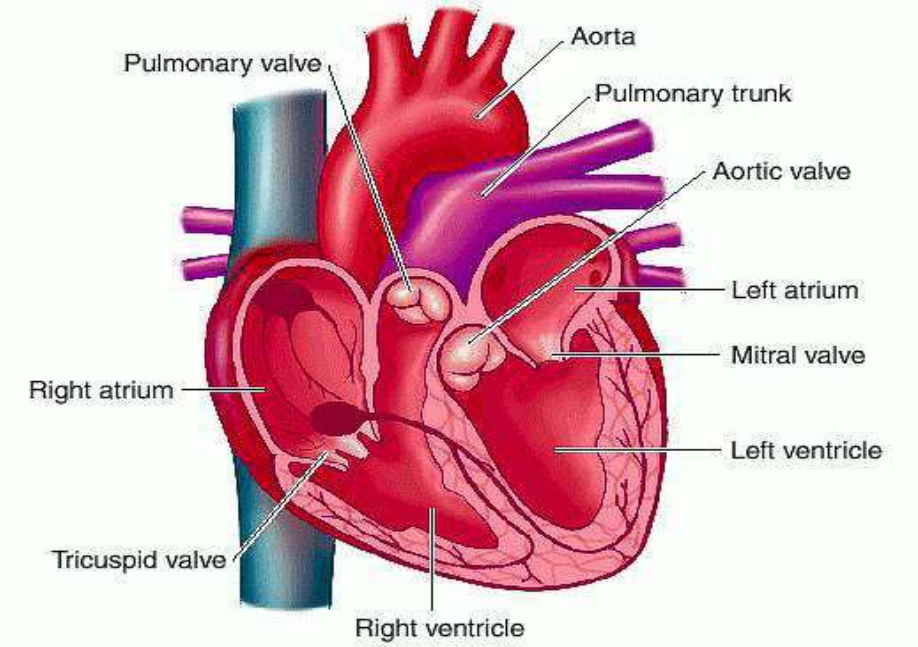
Fueling Muscle Contraction: ATP is the immediate source of energy for muscle contraction. Although a muscle fiber contains only enough ATP to power a few twitches, its ATP "pool" is replenished as needed. There are three sources of high-energy phosphate to keep the ATP pool filled.

- **Creatine phosphate**
- **Glycogen**
- **Cellular respiration** in the mitochondria of the fibers.

Lecture 5 / ----------Circulatory system (Part 1)

Heart Structure of the Cardiovascular System

- The heart is a hollow, muscular organ that is divided into four chambers. The right and left Atria (atrium) receive venous blood from the veins, while the right and left Ventricles pump blood into the arteries. The Heart is made up of a powerful muscle called Myocardium. The size of your heart is a little larger than the size of your fist. The location of the heart is about left-center of your chest.
- Although the heart is a single organ, it functions as 2 separate pumps. The right half pumps blood into the pulmonary circuit, while the left half pumps blood into the systemic circuit.
- A muscular wall called the Septum separates the two halves of the heart. The right side of the heart receives blood low in oxygen. The left side of the heart receives blood that has been oxygenated by the lungs. The blood is then pumped out into the Aorta and to all parts of the body.



Heart Valves

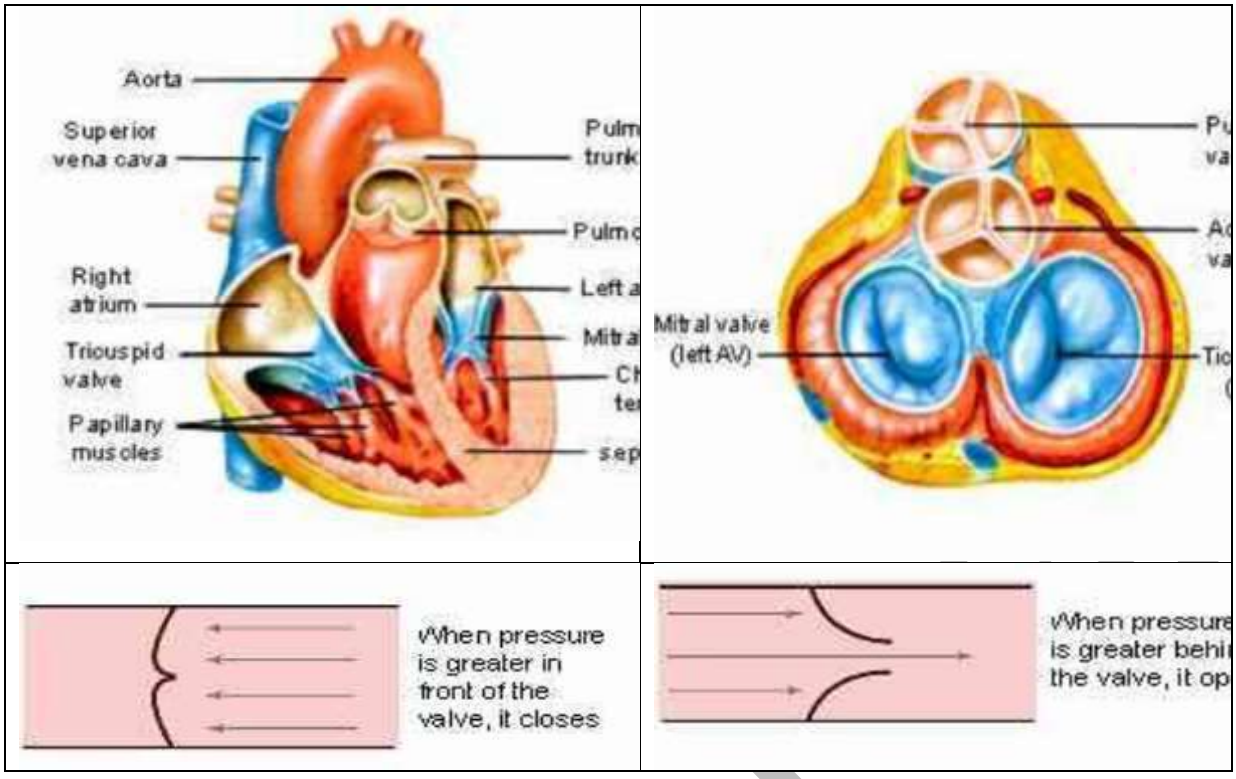
Its function is to ensure a one-way flow of blood through the heart. The valves are composed of sheets of tough connective tissue (**leaflets**) that act like flaps. The opening and closing of the AV valves is dependent on pressure differences between the atria and ventricles. To ensure that the AV valves do not ever (turn inside-out), they are attached to small papillary muscles by tough tendons called the ***Cordaetendineae***. Papillary muscle contract in synchrony with the ventricles, thus maintaining constant tension on the valve leaflets.

A/ **Atrioventricular valves (AV valves)*:*** which separate the atria from the ventricles, allow blood to flow from the atria to the ventricles, but prevent flow in the opposite direction.

- The right AV valves are called the **Tricuspid valve**.
- The left AV valve is called **the Mitral valve**.

B/Semilunar valves (pulmonary valve and aortic valve)*:* are one-way valves that separate the ventricles from major arteries.

- Aortic valve separates the left ventricle from the aorta
- Pulmonary valve separates the right ventricle from the pulmonary artery.



- **The Heart Diagram above and the information that follows will give a better understanding of the heart structure and how the blood circulates through the heart.**

1. **Right Atrium:** is larger than the Left Atrium but has thinner walls. The Right Atrium has two major veins that return blood to the heart from all parts of the body. (The Superior Vena Cava and the Inferior Vena Cava.) .These two veins are sometimes called the "Great Veins". The Superior Vena Cava returns the deoxygenated blood from the upper part of the body and the Inferior Vena Cava returns the deoxygenated blood from the lower part of the body. The Right Atrium also receives blood back from the heart muscle itself. After the blood is collected in the Right Atrium it is pumped into the Right Ventricle through the Tricuspid Valve (three leaf valve).

2. **Left Atrium:** receives blood from four Pulmonary Veins. The blood received from the lungs has been oxygenated. The oxygenated blood that is collected in Left Atrium is then pumped into the Left Ventricle through the Bicuspid Valve.

3. **Right Ventricle:** receives blood from the Right Atrium. When the Heart contract the blood is forced out through the Pulmonary Semilunar Valve into the Pulmonary Artery. The Pulmonary Semilunar Valve is a three flap valve that stops the backflow of blood. The walls of the Right Ventricle are a little thicker than the Right Atrium.

4. **Left Ventricle:** The chamber of the Left Ventricle has walls that are three times the thickness of the Right Ventricle. This is important because the oxygenated blood that

it receives from the Left Atrium has to be pump throughout the body. The Bicuspid Valve closes and the blood is collected in the Left Ventricle. The closing of the Bicuspid Valve stops the backflow of blood. When the Heart muscle contracts the blood is forced through the Aortic Semilunar Valve which has the same features as the Pulmonary Valve. The blood then passes through the Aortic Semilunar Valve into the Aorta.

5. **Aorta:** is the largest blood vessel in the body. The inner diameter of the Aorta is about 1 inch. The Aorta carries oxygenated blood to every other part of the body. The Aorta receives its blood from the Left Ventricle.

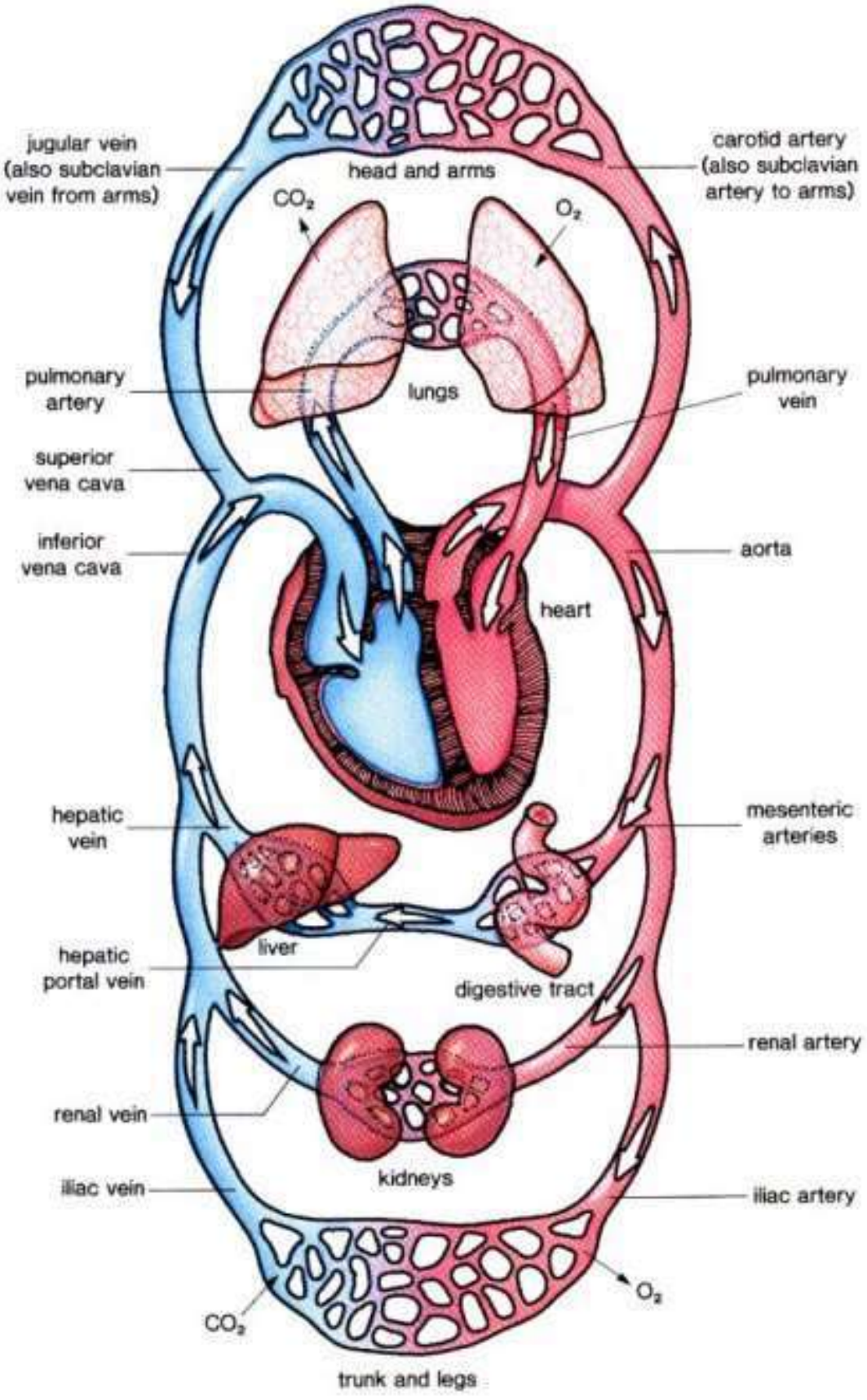
6. **Septum:** is a partition that separates the right and left sides of the Heart. There are two separate regions of the Septum. They are the Inter-atrial Septum that separates the Atriums and the Inter-ventrial Septurm that separates the Ventricles. The Inter-atrial Septum is only present in the fetal period and is open during this period. The Inter-atrial Septum closes at the time of birth. The Interventrial Septum is supposed to be closed all the time but sometimes an opening is present at birth. This would be considered a congenital heart disease.

7. **Superior Vena Cava:** The importance of the Superior Vena Cava is to return blood back to the Right Atrium from the upper part of the body. It is one of the largest veins in the body.

8. **Inferior Vena Cava:** is important for carrying the blood back to the Right Atrium from the lower part of the body.

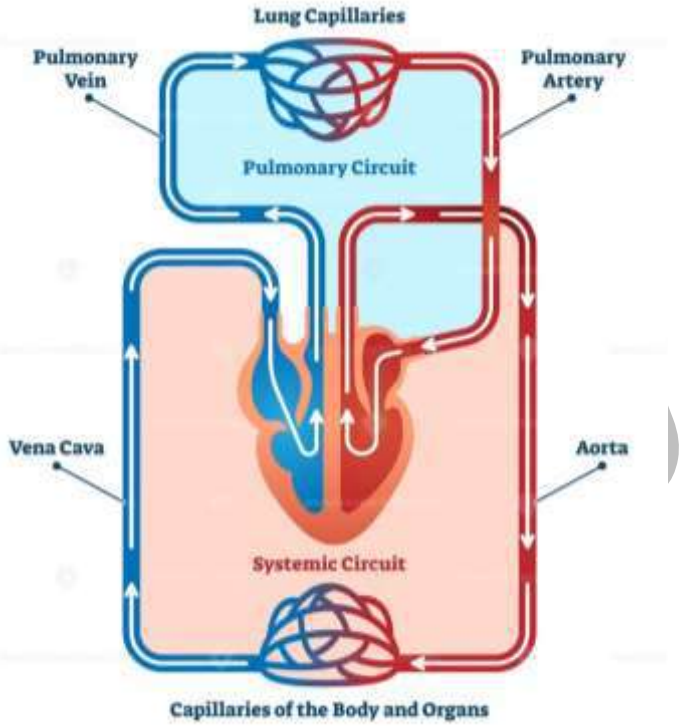
9. **Pulmonary Arteries:** carry the blood from the Right Ventricle to both of the lungs. There the blood is oxygenated and sent to the Left Atrium in the heart.

10. **Pulmonary Veins:** carry the oxygenated blood back to the Left Atrium in the heart**.**


jugular vein
(also subclavian
vein from arms)
head and arms
carotid artery
(also subclavian
artery to arms)
CO_2
O_2
pulmonary
artery
lungs
pulmonary
vein
superior
vena cava
inferior
vena cava
aorta
heart
hepatic
vein
mesenteric
arteries
liver
hepatic
portal vein
digestive tract
renal artery
renal vein
kidneys
iliac vein
iliac artery
O_2
CO_2
trunk and legs

Circulatory pathways:

The blood vessels of the body are functionally divided into two distinctive circuits: Pulmonary circuit and Systemic circuit.

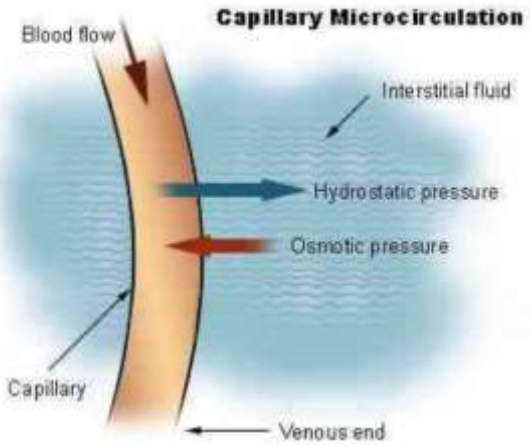


A. Pulmonary circuit: circulates oxygen-poor blood from the right ventricle to the lungs where blood picks up a new blood supply, then it returns the oxygen-rich blood to the left atrium**.**

B. Systemic Circuit: The left ventricle is the pump for the systemic circuit, which provides the blood supply (oxygen and nutrients), through arteries to all body tissue. The deoxygenated (carbon dioxide and waste products) blood returns through a system of veins to the right atrium of the heart.

Physiology of circulation (Role of the capillaries)

In addition to forming the connection between the arteries and veins, capillaries have a vital role in the exchange of gases, nutrients, and metabolic waste products between the blood and the tissue cells. Substances pass through the capillaries wall by Diffusion, Filtration, and Osmosis.



- Oxygen and carbon dioxide move across the capillary wall by diffusion.
- Fluid movement across a capillary wall is determined by a combination of Hydrostatic and Osmotic pressure.

Lecture 6 / ----------Circulatory system (Part 2)

Cardiac cycle

The cardiac cycle is defined as a sequence of alternating contraction and relaxation of the atria and ventricles in order to pump blood throughout the body. It starts at the beginning of one heartbeat and ends at the beginning of another.

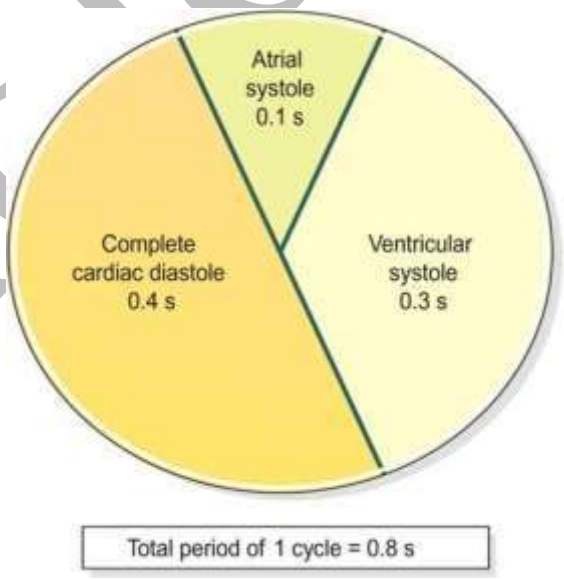
Each cardiac cycle has a diastolic phase (also called **diastole**) where the heart chamber is in a state of relaxation and fills with blood that receives from the veins and a systolic phase (also called **systole**) where the heart chambers are contracting and pumps the blood towards the periphery via the arteries.

Both the atria and the ventricles undergo alternating states of systole and diastole. In other words, when the atria are in diastole, the ventricles are in systole and vice versa.

The frequency of the cardiac cycle is described by the heart rate, which is typically expressed as beats per minute. Each beat of the heart involves five major stages. The first two stages, often considered together as the "ventricular filling" stage, involve the movement of blood from the atria into the ventricles. The next three stages involve the movement of blood from the ventricles to the pulmonary artery (in the case of the right ventricle) and the aorta (in the case of the left ventricle). Under normal circumstances, each cycle takes 0.8 seconds.

Duration of cardiac cycle:

- Out of 0.7 sec of atrial diastole, first 0.3 sec (0.27 sec accurately) coincides with ventricular systole.
- Then, ventricular diastole starts and it lasts for about 0.5 sec (0.53 sec accurately).
- Later part of atrial diastole coincides with ventricular diastole for about 0.4 sec. So, the heart relaxes as a whole for 0.4 sec.



Heart Sounds

Normal heart sounds are caused by the closing of heart valves. As valves snap shut, the walls of the chambers and major arteries vibrate. We hear these vibrations as two distinct sounds (**lub-dup**):

A. The first sound, **"lub"**, is associated with the closing of the AV valves.
B. The second sound, **"dup"**, is associated with the closing of the Semilunar valves.

Heart Murmurs:

Abnormal heart sounds, or murmurs, are usually (but not always) associated with heart disease. Blood flow through the valves should occur in a smooth fashion (laminar blood flow). The severity of heart murmurs varies across a wide range. Mild murmurs are of no consequence, but severe murmurs can significantly affect heart function.

Regulation of the cardiac cycle/ Electrical Activity of the Heart:

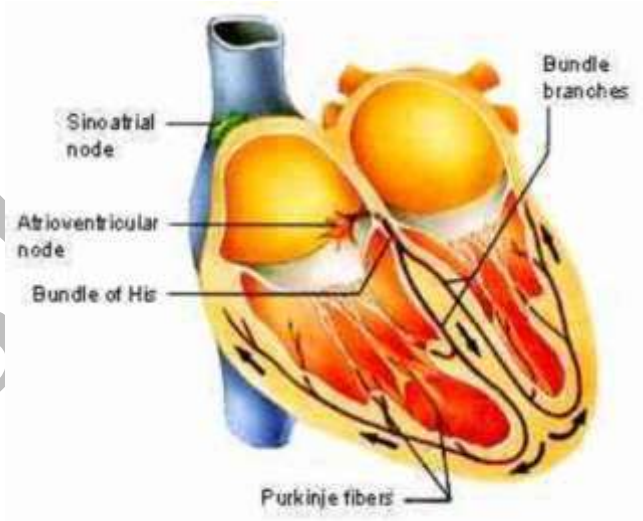
Although the heart is enervated by the autonomic nervous system, the heart does not require the nervous system to function. If all the nerves going into the heart are cut, the heart will continue to beat. This is because the heart is **Autorhythmic,** meaning it generates its own rhythmic action potentials independent of the nervous system.

The rhythmic beating of the heart is controlled by a small group of cells in the wall of the right atrium, collectively called the **Sinoatrial node** (typically referred to as the **SA node**). Because the SA node controls heart rate, it is called the **pacemaker of the heart**. The auto rhythmic cells of the SA node initiate action potentials at a constant rate because they do not have a resting membrane potential.

Rather their membrane potential is always drifting towards threshold. This slow drift toward threshold is called the **pacemaker potential**. When threshold is reached, an action potential is fired. Again the membrane potential drifts toward threshold and another action potential is fired. The cycle of drift and fire repeats itself over and over again in a rhythmic manner. ايقاع

Conduction System

Action potentials that originate in the **SA node** spread to the myocardial cells of the atria through gap junctions between cells.



Depolarization of the atria stimulates contraction of the atrial myocardium. Action potentials cannot directly spread from the atrial myocardium to the ventricular myocardium due to the presence of the non-conducting fibrous skeleton that separates them.

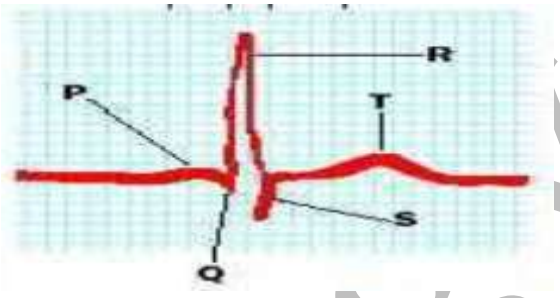
Rather, the impulse travels to the ventricles through a system of specialized cells called the Conduction system.

The conduction system is composed of:

a. **Atrioventricular node (AV node)**
b. **Bundle of His**
c. **Bundle branches**
d. **Purkinje fibers.**

Electrocardiogram

Electrical activity of the heart is recorded in an **Electrocardiogram** (ECG). Here, one complete cycle is shown, comprising contraction and relaxation of the atria and the ventricles. Five waves in the normal electrocardiogram correspond to the movement of ions into and out of muscle cells and the direction of conduction over the heart.



- **P wave** is due to activation of atrial cells.
- **Q, R, S waves** correspond to activation of ventricular muscle cells.
- **T wave** corresponds to the end of the ventricular action potential.
- No wave for the end of the atrial action potential is seen because it occurs at the same time as QRS.

Abnormalities in the size or duration of the electrocardiogram waves can be used to diagnose heart attacks and other forms of heart disease. In abnormal hearts, waves may be missing or out of sequence.

Cardiac Output

Cardiac output is the volume of blood pumped by the heart per minute (mL blood/min). Cardiac output is a function of heart rate and stroke volume. The heart rate is simply the number of heart beats per minute. The stroke volume is the volume of blood, in milliliters (mL), pumped out of the heart with each beat. Increasing either heart rate or stroke volume increases cardiac output.

Cardiac Output in mL/min = heart rate (beats/min) × stroke volume (mL/beat)

Cardiac Output = 70 (beats/min) X 70 (mL/beat)
= 4900 mL/minute.

An average person has a resting heart rate of 70 beats/ minute and a resting stroke volume of 70 mL/beat.

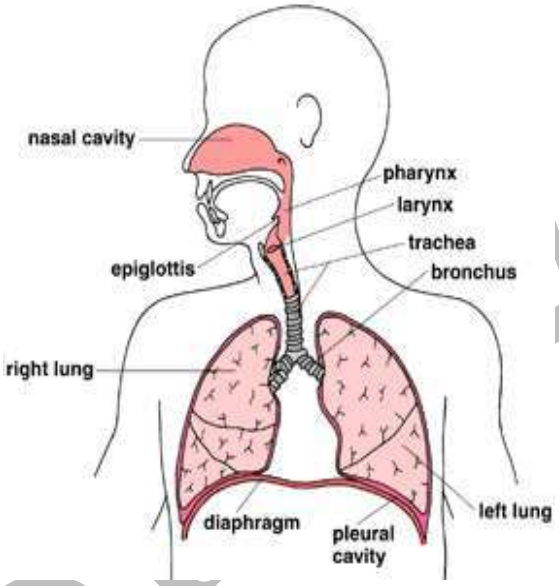
The total volume of blood in the circulatory system of an average person is about 5 liters (5000 mL). According to our calculations, the entire volume of blood within the circulatory system is pumped by the heart each minute (at rest). During vigorous exercise, the cardiac output can increase up to 7 fold (35 liters/minute).

The principle functions of the respiratory system are:

The Human Respiratory System / is divided into two parts, the upper respiratory tract and the lower respiratory tract. The following are the organs of the upper and the lower respiratory tract.

A-The Upper Respiratory Tract

- Nose (nostrils) - It is the entrance of the respiratory tract.
- Pharynx - It is situated behind the mouth and is the passage to the stomach and the lungs.
- Larynx - It is present at the top of trachea and contains vocal cords. It is also known as the voice box.
- Trachea (windpipe) - It is a tube-like structure that helps in passage of air from larynx to the bronchi.



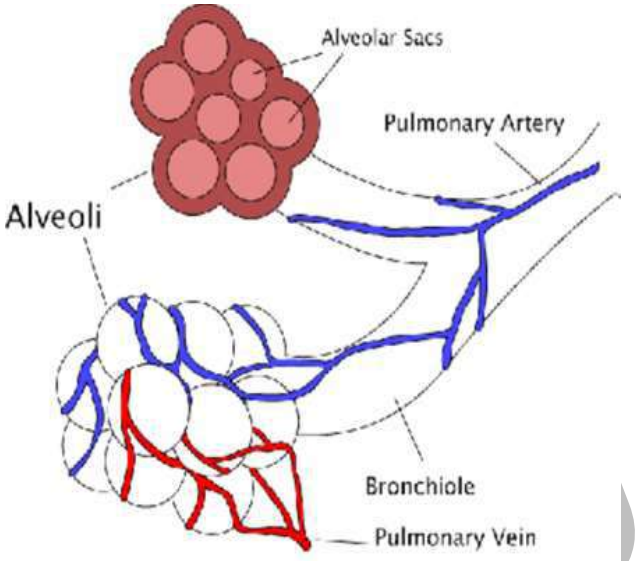
B-The Lower Respiratory Tract

- Bronchi (bronchioles) - These are the branches of the bronchi that conduct air into the lungs.
- Alveoli (air sacs) - The sacs in the lungs where gas exchange occurs.
- Lungs - The two inverted-cone shaped organs present in the chest of human beings

Pulmonary alveolus

An **alveolus** (plural: **alveoli**), is an anatomical structure that has the form of a hollow cavity. In the lung, the **pulmonary alveoli** are spherical outcroppings of the respiratory bronchioles and are (the primary sites of gas exchange with the blood).

The lungs contain about 700 million alveoli, representing a total surface area of 70-90 meters squared, each wrapped in a fine mesh of capillaries. The alveoli have radii of about 0.1 mm and wall thicknesses of about 0.2 μm. The alveoli consist of an epithelial layer and extracellular matrix surrounded by capillaries. In some alveolar walls there are pores between alveoli. There are two major alveolar cell types in the alveolar wall (Pneumocytes):



- **Type I cells that form the structure of an alveolar wall**
- **Type II cells that secrete surfactant to lower the surface tension of water**

The alveoli have an innate tendency to collapse because of their spherical shape, small size, and surface tension due to water vapor, Phospholipids, which are called surfactants and pores, help to equalize pressures and prevent collapse

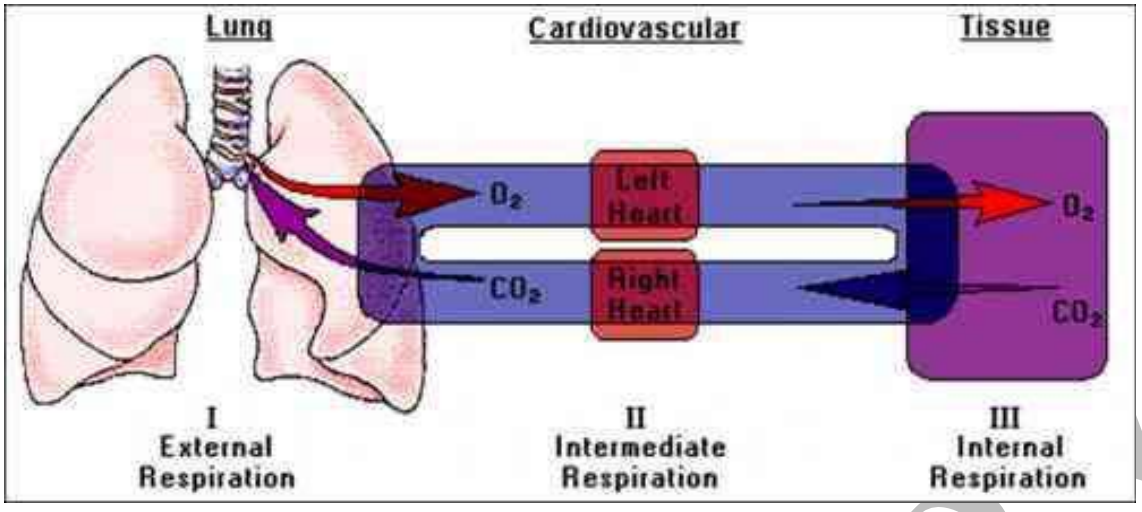
Respiration: Is the act of breathing .In terms of animal physiology, respiration is simply defined as the process in which oxygen from the environment enters the body and the carbon dioxide leaves it. The process of respiration takes place in four stages:

1. **Ventilation/** The air moves in and out of the alveoli present in the lungs.
2. **Pulmonary gas exchange/** that take place between pulmonary capillaries and alveoli. (External Respiration)
3. **Gas transport/** is the process in which the gas moves within pulmonary capillaries, towards the peripheral capillaries present in the organs and then back to the lungs.
4. **Peripheral gas exchange/** the process in which the gases are exchanged between the organs / tissues and tissue capillaries. (Internal Respiration)

External Respiration: When a breath is taken, air passes in through the nostrils, through the nasal passages, into the pharynx, through the larynx, down the trachea, into one of the main bronchi, then into smaller bronchial tubules, through even smaller bronchioles, and into a microscopic air sac called an alveolus. It is here that external respiration occurs.

Simply put, it is the exchange of oxygen and carbon dioxide between the air and the blood in the lungs.

Internal Respiration: The body tissues need the oxygen and have to get rid of the carbon dioxide, so the blood carried throughout the body exchanges oxygen and carbon dioxide with the body's tissues. (Is basically the exchange of gasses between the blood in the capillaries and the body's cells).



FACTORS OF NORMAL RESPIRATION

1) Elastic recoil of the lungs: It is the tendency of the lung to return to its original volume when stretched, Contributes to occurrence of expiration, **Due to:**

- Elastic fibers; elastin + collagen fibers (responsible for 1/3 of recoil).
- Surface tension of fluid lining alveoli (responsible for 2/3 of recoil).

2) The lung surfactant: It is a lipoprotein substance secreted by alveolar epithelium into the alveoli. It is secreted among the fluid molecules.

Function:

1- **Decreasing the attraction between them and lowering the surface tension of the fluid lining the alveoli.**
2- **Prevention of collapse of small alveoli especially during expiration.**
3- **Decrease of muscular effort needed to ventilate the lungs.**
4- **It has an immune effect to protect the lungs against invaders.**

3) Compliance: is a measure of the ease of inflation of the lungs (measure of dispensability). Measured as the change in lung volume for a certain change in transpulmonary pressure. When a small change in pressure causes a large change in volume, this is expressed as a highly compliant lung.

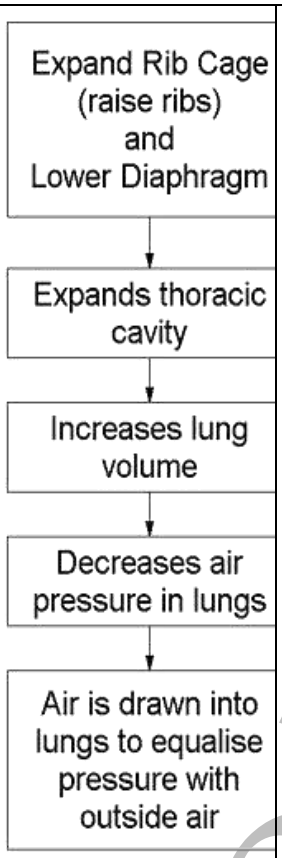
Lecture 7 / ----------Respiratory system

Breathing Cycle:

Normal adult breathes about 12-16 breaths or cycles/min. It takes place about (3.7 sec) and includes 2 phases followed by a pause, each phase includes the following mechanisms

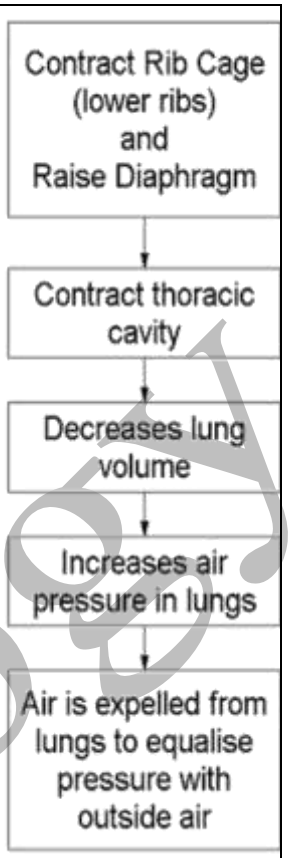
A-Inspiration: (the flow of air from atmosphere into the lungs).

During inspiration, the diaphragm and the intercostal muscles contract. The diaphragm moves downwards increasing the volume of the thoracic (chest) cavity, and the intercostal muscles pull the ribs up expanding the rib cage and further increasing this volume. This increase of volume lowers the air pressure in the alveoli to below atmospheric pressure. Because air always flows from a region of high pressure to a region of lower pressure, it rushes in through the respiratory tract and into the alveoli. This is called negative pressure breathing, changing the pressure inside the lungs relative to the pressure of the outside atmosphere. These two processes increase the volume of the thoracic cavity and also reduce the air pressure to below atmospheric pressure allowing air to rush into the airways then into the alveoli.



B-Expiration: (the flow of air from atmosphere into the lungs)

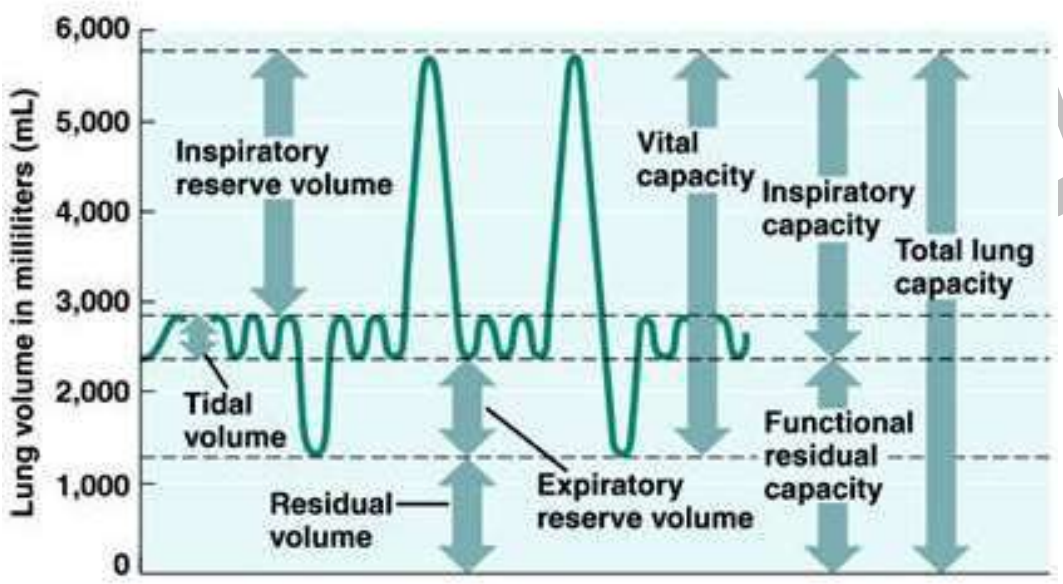
In contrast to inspiration, during expiration the diaphragm and intercostal muscles relax. This returns the thoracic cavity to its original volume, increasing the air pressure in the lungs, and forcing the air out.



Respiratory values

- ***Total lung capacity (TC),*** about six liters, is all the air the lungs can hold.
- ***Vital capacity (VC)*** The maximum volume of air that can be expelled at the normal rate of exhalation after a maximum inspiration.
- ***Tidal volume (TV)*** is the amount of air breathed in or out during normal respiration. It's normally from 450 to 500 ml.
- ***Residual volume (RV)***is the amount of air left in the lungs after a maximal exhalation. This averages about 1.5 L.

- ***Expiratory reserve volume (ERV)*** is the amount of additional air that can be breathed out after normal expiration. This is about 1.5 L.
- ***Inspiratory reserve volume*** similarly, is the additional air that can be inhaled after a normal tidal breath in. About 2.5 more liters can be inhaled.
- ***Functional residual capacity,*** **(ERV + RV),** is the amount of air left in the lungs after a tidal breath out.
- ***Inspiratory capacity (IC)*** is the volume that can be inhaled after a tidal breath out.
- Anatomical dead ***space*** is the volume of the airways.



Alveolar ventilation:

This is the volume of air that moves into and out of the alveoli per minute. It is equal to the tidal volume minus the anatomical dead space, multiplied by the respiratory rate:

$$\boldsymbol{Alveolar\ ventilation} = (\boldsymbol{Tidal\ volum - Anatomical\ dead\ space}) \times \boldsymbol{respiratory\ rate}$$

$$= (\mathbf{500 - 150})\boldsymbol{ml} \times \mathbf{15}\ \boldsymbol{per\ minute}$$

$$= \mathbf{5.25}\ \boldsymbol{liter\ per\ minute}$$

Lung function tests are carried out to determine respiratory function and are based on the parameters out lined above. Results of these tests can help in diagnosis and monitoring of respiratory disorders.

Exchange of gases:

- Breathing involves the alternating processes of inspiration and expiration.
- Diffusion of oxygen (O_2) and carbon dioxide (CO_2) depends on **<u>Pressure differences</u>**, e.g. between atmospheric air and the blood, or blood and the tissues.
- Gases move across a sem-ipermeable membrane by diffusion from the higher concentration to the lower until equilibrium is established.
- The differences between oxygen and carbon dioxide concentrations are measured by
-

- **Partial pressures.**

Composition of air and partial pressure of gases:

Atmospheric pressure at sea level is 760 mmHg .With increasing height above sea level ,atmospheric pressure is progressively reduced at 5500 m ,about two-thirds the height of mount Everest (8850 m) it is about half that at sea level.

Air is a mixture of gases: Nitrogen, Oxygen, Carbon dioxide, Water vapor and small quantities of inert gases. The percentage of each in inspired and expired air is listed in the table below:

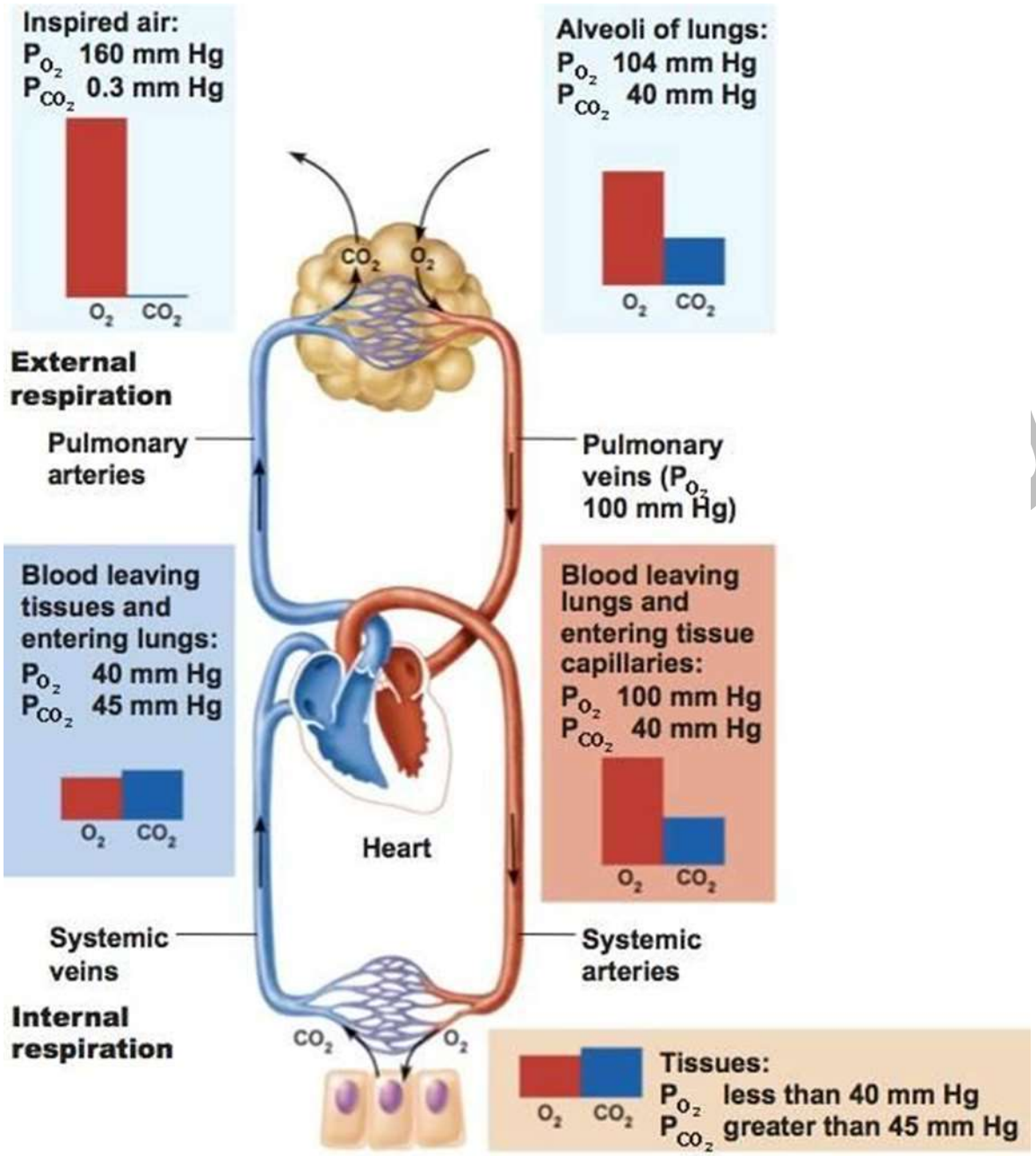
Table 1 : The composition of inspired and expired air.

	Inspired air (%)	Expired air (%)
Oxygen	21	16
Carbon dioxide	0.04	4
Nitrogen	78	78
Water vapor	Variable	Saturated

Atmospheric nitrogen is not used by the body so its partial pressure remains unchanged and is the same in inspired and expired air, alveolar air and in the blood. Each gas in the air mixture exerts a part of the total pressure proportional to the concentration .i.e, the partial pressure (Table 2), this is denoted as: e.g. PO_2, PCO_2.

Table 2: Partial pressure of gases in the human body.

Air components	Alveolar air	Deoxygenated blood	Oxygenated blood
Oxygen	100	40	100
Carbon dioxide	40	45	40
Nitrogen and other inert gases	573	573	573
Water vapor	47		
	760		



Transport of gases in the blood stream:

Oxygen and carbon dioxide are carried in the blood in different ways:

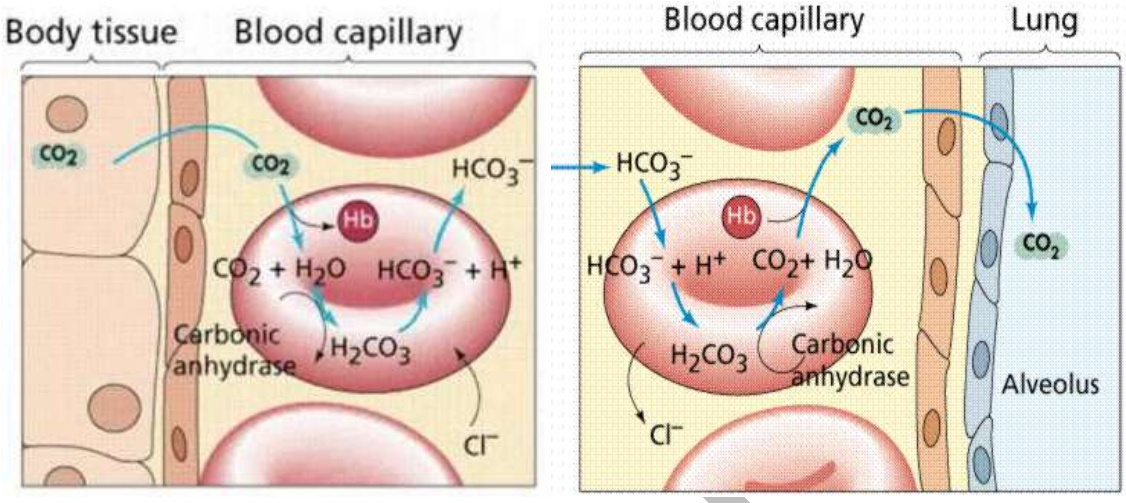
Oxygen is carried in the blood in:

- Chemical combination with haemoglobin as ***Oxyhaemoglobin***(98.5%)
- Solution in plasma water (15%)

Oxyhaemoglobin is unstable and under certain conditions readily dissociates releasing oxygen. Factors that increase dissociation include: Low O_2 levels, low pH and raised temperature. In active tissues there is increased production of CO_2 and heat, which leads to increased release of O_2. In this way O_2 is available to tissues in greatest needs, whereas oxyhaemoglobin is bright red, deoxygenated blood is bluish-purple in color.

Carbon dioxide is one of the waste products of metabolism .its excreted by the lungs and is transported by three mechanisms:

- As Bicarbonate ions (HCO_3^-) in the plasma (70%)
- Some is carried in the erythrocytes, loosely combined with haemoglobin as ***Carbaminohaemoglobin*** (23%)
- Some is dissolved in the plasma (7%)



Lecture 8 / ----------Urinary system (Part 1)

Functions of the Urinary System

Structure of the Kidneys:

Nephrons: are the basic structural and functional units of the kidney. Each kidney contains approximately 1 million nephrons distributed in the form of 10-20 cone-shaped tissue units called ***renal pyramids*** that span both the inner and outer portions of the kidney, the ***renal medulla*** and ***renal cortex***.

The Nephron consists of a network of tubules and canals specialized in filtration. Each nephron is made of intricately interwoven capillaries and drainage canals to filter wastes, macromolecules, and ions from the blood to urine. There are two main parts of a nephron:

- ***Renal corpuscle*** / is the initial filtering component of the nephron and is made up of two structures known as:
    - Bowman's capsule is a double membrane that cups the glomerulus.
    - Glomerulus is a capillary extension, a small network of thin blood vessels, receiving blood from the renal circulation.
      (The glomerular filtration rate is a measure of kidney function).

- ***Renal tubule***. / are duct system beginnings at the Bowmen's capsule in the cortex, looping through the renal medulla, and returning to the cortex to connect to the ***Collecting duct system***. Each renal tubule is divided into:
    - Proximal convoluted tubule has a brush border that is microvilli, that increases the surface area for absorption.
    - Loop of Henle,
    - Distal convoluted tubule.

Table / This table summarize the essential functions of the major segments of the Nephron.

The kidneys have three basic mechanisms for separating the various components of the blood: **Filtration, Reabsorption**, and **Secretion**. These three processes occur in the ***Nephron***

Nephron Segment	Function
Renal Corpuscle: • Glomerulus • Bowman's capsule	**Filtration:** Glomerulus filters proteins and cells from the blood. All other bloodcomponents pass into Bowman's capsule, then into the tubule.
U-Shaped Tubule • Proximal convoluted tubule • Loop of Henle • Distal convoluted tubule.	**Reabsorption and Secretion:** Semipermeable membranes surrounding the tubule allow selectivepassage of particles back into the blood (reabsorption), or from theblood into the tubule (secretion).
Collecting Duct	**Collection:** Collects all material that has not returned to the blood through thetubular membranes. This material exits the kidney as urine.

Nephron Function

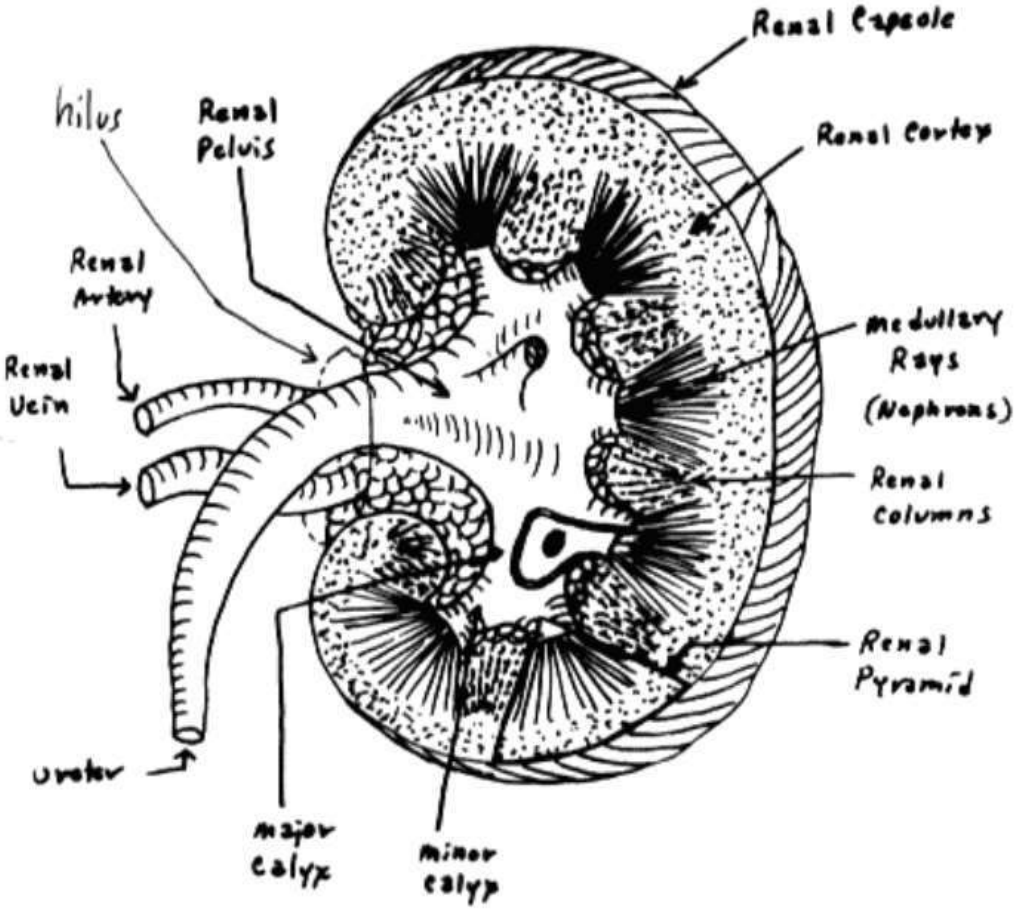
The blood is filtered and urine formed by the actions of the nephrons. In each nephron, high pressure in the glomerulus pushes water and small dissolved materials into the extravascular space of the Bowman's capsule and into the tubule. The proximal tubule reabsorbs water, salts, glucose, and amino acids to maintain electrolyte levels in the body.

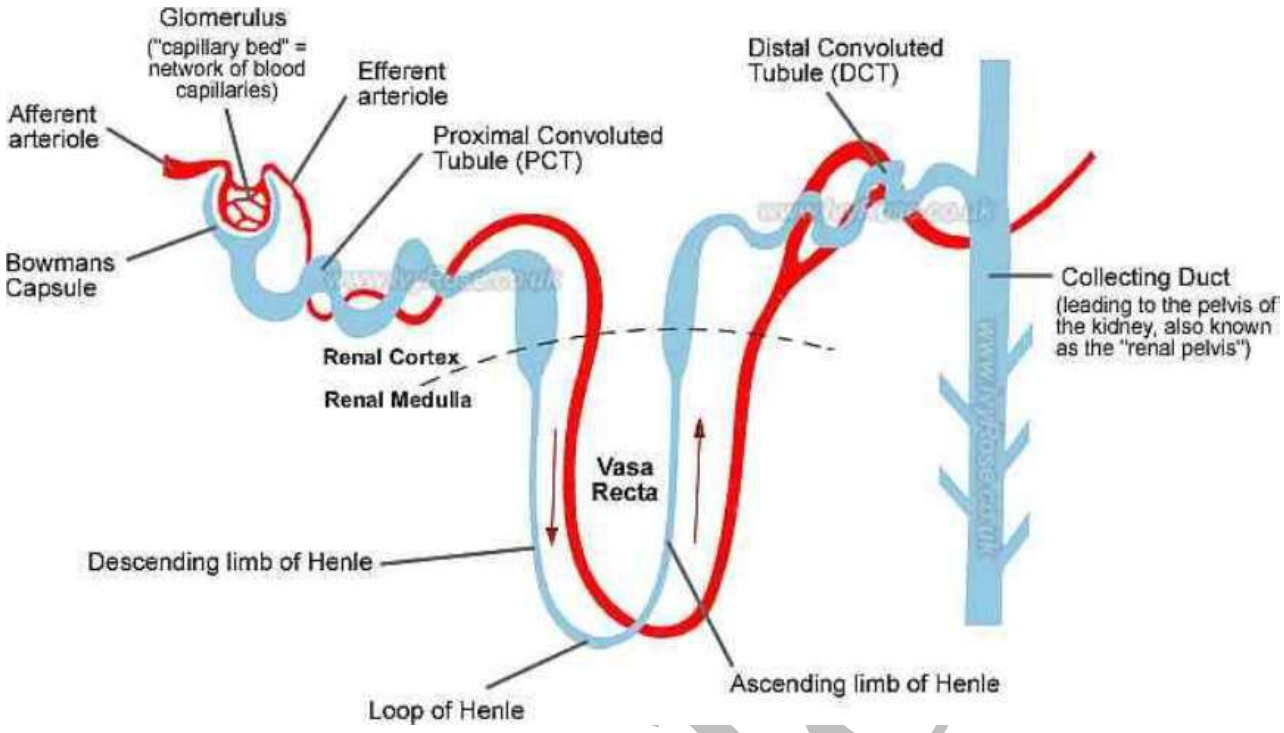
The interstitial of, that is the tissue space surrounding, the loop of Henle concentrates salts that will be excreted in the urine, creating a concentration gradient in the medulla. The limbs of Henle's loop are permeable to particular ions (Descending, water and some urea; thin Ascending, general ions; Medullary thick ascending – sodium, potassium, chloride), with the cortical thick ascending limb draining into the distal convoluted tubule. The distal tubule contains cells specialized in active transport and maintains urine and blood pH levels, particularly through the regulation of sodium and potassium.

Filtration and Urine Formation

The kidneys filter blood and produce urine. They filter out wastes and excess ions, which leave the body in the urine, and return any, needed substances back to the blood. In 1 day, the kidneys filter over 140 liters of blood (the body's entire volume of blood is filtered every 40 minutes).The kidneys produce urine through 3 processes:

1. **Filtration** / Water, solutes smaller than proteins and most wastes passively pass out of the glomerulus capillaries into a cupped region called the Bowman's capsule. This fluid is called filtrate. Proteins and blood cells cannot pass through and so are not parts of the filtrate.
2. **Reabsorption** /The filtrate moves into tubules that recover most of the nutrients, water, and essential ions from the filtrate and return it to the blood of capillaries in surrounding connective tissue. What is left becomes "urine" and is eventually excreted out**.**
3. **Secretion** /This process take any wastes not filtered by the glomerulus (from the blood of surrounding capillaries) and add them to the urine.





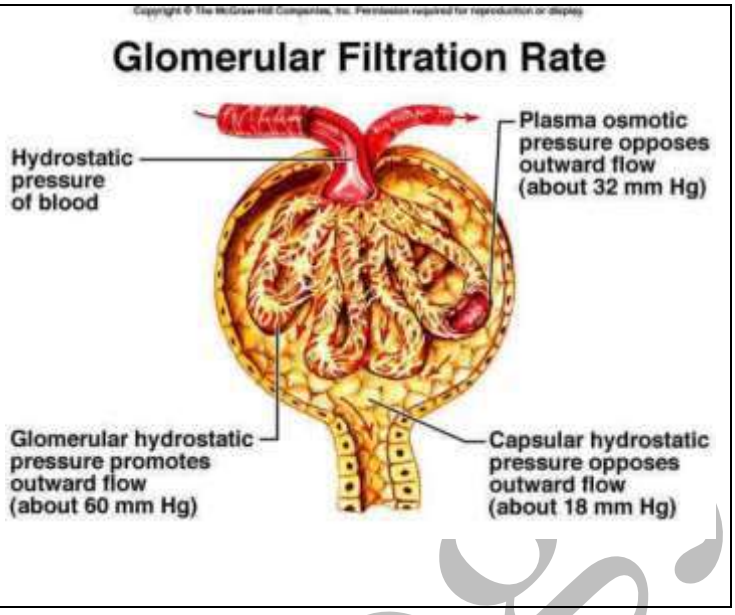
Glomerular Filtration

Blood enters the kidney via the renal artery, eventually forming many afferent arterioles, each of which delivers blood to an individual kidney nephron.The diameter of the afferent (incoming) arteriole is greater than the diameter of the efferent arteriole (by which blood leaves the glomerulus). The pressure of the blood inside the glomerulus is increased due to the difference in diameter of the incoming and out-going arterioles. This increased blood pressure helps to force the following components of the blood out of the glomerular capillaries: (Most of the water; Most/all of the salts; Most/all of the glucose; Most/all of the urea). Blood cells and plasma proteins are not filtered through the glomerular capillaries because they are relatively larger in physical size.

The water and salts that have been forced out of the glomerular capillaries pass into the Bowman's capsule and are called the ***Glomerular filtrate.*** This glomerular filtrate isformed at a rate of above 125 Cm^3 per minute in humans. This volume is 40 approximately 20% of the plasma delivered during that time. (*Again: It contains all the materials present in the blood except blood cells and most proteins – which are too large to cross the basement membrane of the glomerulus).*

The glomerular filtrate passes from the renal corpuscle to the renal tubule: Glomerular filtrate fills the capsular space, and is formed by a net filtration pressure (NFP) of 10 mm Hg.

- Blood Hydrostatic Pressure = 60 mm Hg)
- Blood Colloid Osmotic Pressure = 32 mm Hg
- Capsular Hydrostatic Pressure = 18 mm Hg).
- 32+18 =50
- 60-50 =10 → Net **filtration pressure (NFP)**



Glomerular filtration rate (GFR)

Is the volume of fluid filtered from the renal (kidney) glomerular capillaries into the Bowman's capsule per unit time? The glomerular filtration rate (GFR) is a measurement of how well the kidneys are processing wastes. The GFR determines the stage of chronic renal disease.

GFR can be calculated by measuring any chemical that has a steady level in the blood, and is freely filtered but neither reabsorbed nor secreted by the kidneys. The rate therefore measured is the quantity of the substance in the urine that originated from a calculable volume of blood. The GFR is typically recorded in *units of volume per time*, e.g. Milliliters per minute (ml/min).

There are several different techniques used to calculate or estimate the glomerular filtration rate. GFR is the best overall index of kidney function. Normal GFR varies according to age, sex, and body size, and declines with age.

Lecture 9 / ----------urinary system (Part 2)

Tubular Reabsorption

Reabsorption varies according to the body's needs, enabling the body to retain most of its nutrients. The processes of tubular reabsorption occur in the following order:

1/ In the Proximal convoluted tubule (PCT) / Most of the volume of the filtrate solution is reabsorbed in the proximal convoluted tubule (PCT). This includes some water and most/all of the glucose (except in the case of diabetics).

Most of the energy consumed by the kidneys is used in the reabsorption of sodium ions (Na^+), which are dissolved in the water component of the filtrate solution. As the

concentration of Na^+ in the filtrate solution are high (about the same as the concentration of Na^+ in blood plasma), Na^+ moves from the tubular fluid into the cells of the PCT.

Symporters simultaneously facilitate passage through the PCT membrane of both Na^+ and another substance/solutes, that are reabsorbed with Na+ in this way include glucose (an important type of sugar), amino acids, lactic acid, and bicarbonate ions (HCO^3). These then move on through cells via diffusion.

Following the movement of solutes (including Na^+), water is then also reabsorbed by osmosis. About 80% of the filtrate volume is reabsorbed in this way.

2/ In the Loop of Henle / The remaining water (together with the dissolved salts and urea) pass from the PCT into the descending limb of Henle. It then passes along the Loop of Henle, and up the ascending limb of Henle.

1. Descending Limb of Loop of Henle / The epithelium lining of the descending limb of Henle is *relatively permeable to water - much less permeable to the salts Na^+ and Cl^-, and to urea*. Therefore, water gradually moves from the descending limb and into the interstitium (surrounding the tubules).

2. Thin Ascending Limb of Loop of Henle / The thin ascending limb of Henle differs from the descending limb in that it is *impermeable to water (so the water that is inside the tubule at this stage generally remains inside it), but is highly permeable to Na^+ and Cl^-, and somewhat permeable to urea*.

3. Thick Ascending Limb of Loop of Henle / The thick ascending limb of Henle, reabsorbs NaCl from the tubular fluid via a different transport process from that of the thin ascending limb of Henle.

3/ In the Distal convoluted tubule (PCT) /the water, urea, and salts contained within the ascending limb of Henle eventually pass into the distal convoluted tubule.

Glucose and Amino Acids Reabsorption

Glucose and amino acids in the blood are easily filtered by the glomeruli into the renal tubules. These molecules are usually not present in the urine. It can be therefore concluded that filtered glucose and amino acids are normally completely reabsorbed by the nephrons. This occurs in the PCT by active transport which is mediated by membrane carriers that can transport (glucose and Na^+) , or (amino acids and Na^+).

Since this mechanism utilizes a fixed number of carrier molecules, the ability of the system to remove all of the glucose from the filtrate will depend upon the level of glucose in the blood. Normally, all of the glucose in the filtrate is returned to the blood.

In a diabetic, the level of glucose is so high that the number of carrier molecules becomes inadequate and glucose remains in the urine.

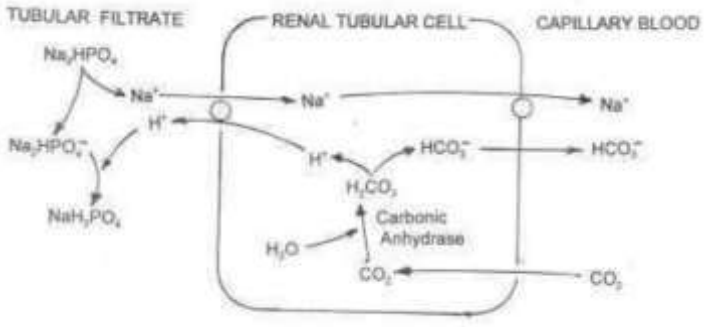
Tubular Secretion

The third process by which the kidneys clean blood (regulating its composition and volume) is called tubular secretion and involves substances being added to the tubular fluid. This removes excessive quantities of certain dissolved substances from the body, and also maintains the blood at a normal healthy pH (which is typically in the range pH 7.35 to pH 7.45). The substances that are secreted into the tubular fluid (for removal from the body) include:

- Potassium ions (K^+)
- Hydrogen ions (H^+)
- Ammonium ions ($NH4^+$)
- Creatinine,
- Urea
- Some hormones
- Some drugs (e.g. penicillin).

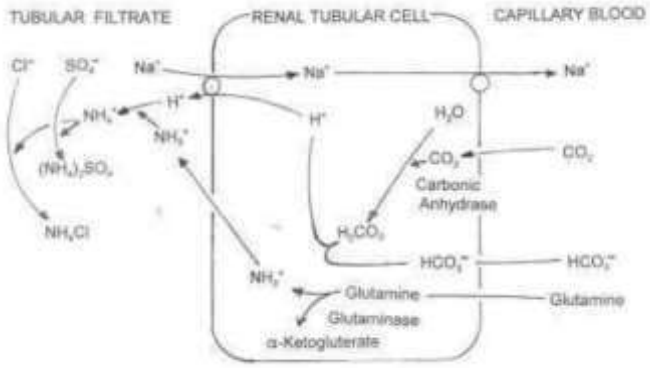
Tubular secretion occurs from the epithelial cells that line the renal tubules and collecting ducts. It is the tubular secretion of H^+ and NH_4^+ from the blood into the tubular fluid (i.e. urine) that helps to keep blood pH at its normal level. The movement of these ions also helps to conserve sodium bicarbonate ($NaHCO_3$). The typical volume of urine produced by an average adult is around 1.5 - 2.0 dm^3 per day.

Hydrogen ion excretion and the formation of phosphates. Refer to following illustration. This mechanism dependent upon the presence of disodium phosphates (Na_2HPO_4) in the glomerular filtrate. The dietary process of the body produces phosphoric acids which are rapidly converted to neutral phosphate salts (disodium phosphate). In the presence of hydrogen ions, the disodium phosphates become monosodium phosphates, which are secreted in the urine. Monosodium phosphates are known as titratable acids.



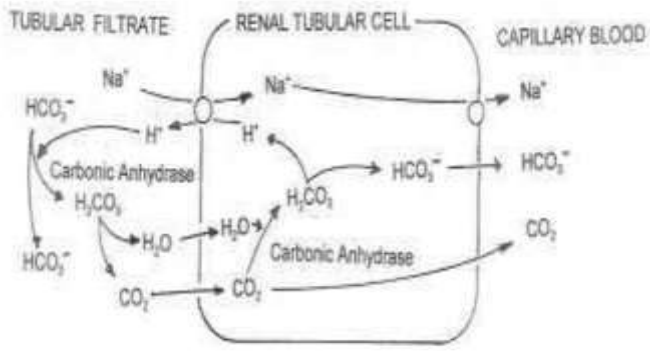
Hydrogen Ion Excretion and Phosphate Formation.

Hydrogen ion secretion and the formation of ammonium ions. Refer to the following illustration. The amino acid glutamine is transferred from peritubular capillary blood to the renal cells where the enzyme glutaminase removed the α-nitrogen, combining it with ahydrogen ion to form ammonia (NH_3) and ketoglutarate. Ammonia is soluble and toxic anddiffuses into the tubular lumen where it combines with hydrogen ions to form ammoniumions. Ammonium ions are non-diffusible and remain in the lumen of the tubule where theycombine with neutral salts (NaCl, Na_2SO_4) and voided as a urinary constituent.



Hydrogen Ion Excretion and Ammonia Formation.

Hydrogen ion secretion and bicarbonate ion conservation. Bicarbonateions in the lumen of the tubule react with hydrogen ions to form carbonic acid. Carbonicacid dissociates into carbon dioxide (CO_2) and water by carbonic anhydrase. CO_2 and waterdiffused into the renal cells and catalyzed by carbonic anhydrase is converted back tocarbonic acid which dissociates into hydrogen ion and bicarbonate. The hydrogen ion isreturned to the tubule and bicarbonate ion will diffuse to the blood and resupply thebicarbonate buffer system in blood.



Hydrogen Ion Excretion and Bicarbonate Ion Conservation.

Lecture 10 / ---------- Digestive system

Digestive system is composed of:

A. **The digestive or alimentary tube** or tract (starting from the mouth and ending at the anus). The human digestive system is a coiled, muscular tube (6-9 meters long when fully extended). The organs of the digestive tract are mouth, esophagus, stomach, intestine (small and large) and anus.
B. **Accessory digestive organs** that help in the digestion process. The organs, liver and pancreas produce digestive juices or enzymes that help in breaking down the complex food substances (e.g. fats and lipids) into simpler forms.

The digestive system works in coordination with the **circulatory system** and nervous system, for digestion and supplying energy to the body parts.

Phases of Digestion

1. Cephalic Phase: Preparation for digestion begins with the cephalic phase. Saliva is produced in our mouth while digestive enzymes are produced in the stomach and small intestines. Saliva softens the food we eat to make it easier for the stomach to break it down easily.

2. Mechanical Digestion: This phase of digestion physically breaks down the food into smaller pieces. Mechanical digestion is basically chewing the food.

3. Chemical Digestion: Chemical digestion also begins with the mouth, but differs in process with its mechanical counterpart. This process starts with the saliva softening the food we eat then passing it through the esophagus to the stomach. Here, digestive enzymes break it down into smaller components for easy absorption and assimilation into the blood stream

4. Absorption Phase: This phase defines the movement and distribution of nutrients from the stomach (digestive system) to the lymphatic and circulatory capillaries.

5. Egestion Phase: This phase defines the removal of undigested material from the stomach through the small intestines, large intestines, and out through the anus -- or simply termed as defecation.

Organs of the Digestive System and their Function

Upper Gastrointestinal Tract

The function of the upper gastrointestinal tract is simplification of food into nutrients that can be assimilated by the lower gastrointestinal tract into the human body.

Mouth → Pharynx → Esophagus → Stomach

Mouth: The first organ that directly contributes to the digestion process is the mouth. The mouth is further divided into three basics organs, namely the:

Salivary glands	Produce saliva that exits into the mouth. The saliva acts as lubrication for the food products, when they are being chewed.
Tongue	helps in chewing and swallowing, which is also known as deglutition
Teeth	are also responsible for physical breakage of food.

Pharynx and Esophagus: The next digestive organ is the pharynx, which lies behind the mouth or the buccal cavity. The pharynx prevents the food from entering the voice box or *larynx*. Instead, the pharynx diverts the food to the esophagus, a muscular tube that connects the mouth to the stomach. Though, the pharynx and esophagus are not directly related to the actual simplification of food.

Stomach: The organ of the human body that conducts the mammoth task of breaking food is the stomach. The stomach is divided into four parts:

- ***Cardia*** is the receiver of food from the esophagus.

- ***Fundi, the curvature of the organ were*** food is handed.
- ***Corpus*** body, the central part of the stomach which contributes to the breakage of food.
- ***Antrum*** which conveys it to the smaller intestine.

Within the stomach, the food is broken down into simpler nutrients, like vitamins, carbohydrates, proteins etc.

There are two main kinds of digestion processes in the stomach:

- **Mechanical**/ is defined by the stomach's mixing of the chyme, the stomach also mechanically churns the food.

- **Chemical**/ is defined by the action of various acids, hormones, and enzymes on the chyme.

Chyme, the mix of acid and food in the stomach, leaves the stomach and enters the small intestine Carbohydrate digestion, begun by salivary amylase in the mouth, continues in the bolus as it passes to the stomach. The bolus is broken down into acid chyme in the lower third of the stomach, allowing the stomach's acidity to inhibit further carbohydrate breakdown.

The gastric epithelial lining consists of ***Rugae*** that contain microscopic ***Gastric pits***, each branching into four or five gastric glands made up of highly specialized epithelial cells. The makeup of gastric glands varies with their anatomic location.

- Glands within the gastric cardia comprise <5% of the gastric gland area and contain mucous and endocrine cells.
- The majority of gastric glands (75%) is found within the oxyntic mucosa and contain mucous neck, parietal, chief, endocrine, and enterochromaffin cells.
- Pyloric glands contain mucous and endocrine cells (including gastrin cells) and are found in the antrum.

Gastric juices

Gastric acid is a secretion produced in the stomach. Epithelial cells line inner surface of the stomach secretes about 2 liters of gastric juices per day. Gastric juice contains **hydrochloric acid, pepsinogen**, and **mucus**; ingredients important in digestion.

Chemically it is an acid solution with a pH of 1 to 2 in the stomach lumen, consisting mainly of hydrochloric acid (HCl) (around 0.5%, or 5000 parts per million), and large quantities of potassium chloride (KCl) and sodium chloride (NaCl).

Gastric acid is produced by Parietal cells (also called Oxyntic cells) in the stomach. These cells are part of epithelial fundic glands in the gastric mucosa.

Hydrochloric acid (HCl) lowers pH of the stomach so pepsin is activated. Pepsin is an enzyme that controls the hydrolysis of proteins into peptides. The inactive form of pepsin is pepsinogen which produced by the chief cells in the stomach. Pepsin is an extremely powerful protein digestive enzyme. Gastric acid activates pepsinogen into pepsin–this

enzyme then helps digestion by breaking the bonds linking amino acids, a process known as proteolysis.

In the duodenum, gastric acid is neutralized by sodium bicarbonate from the pancreas. The neutralization is described by the equation:

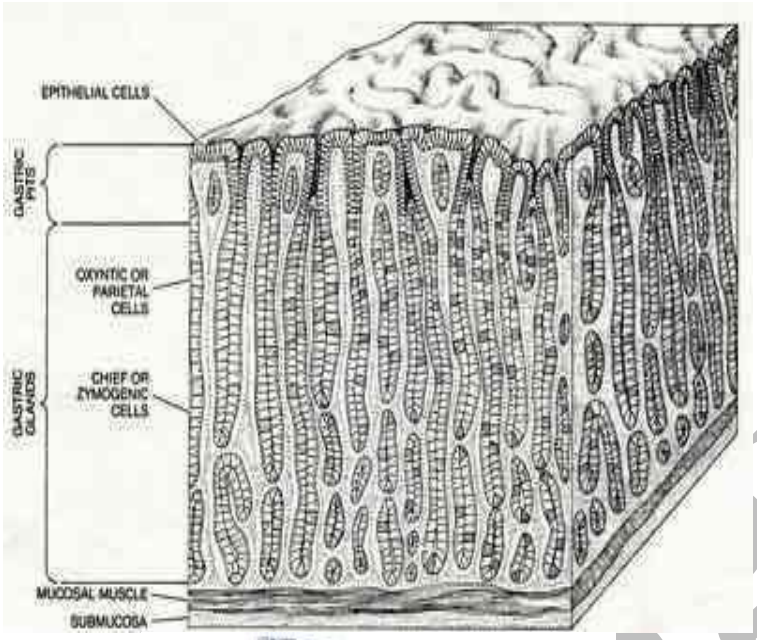
$$HCl + NaHCO_3 \rightarrow NaCl + H_2CO_3$$

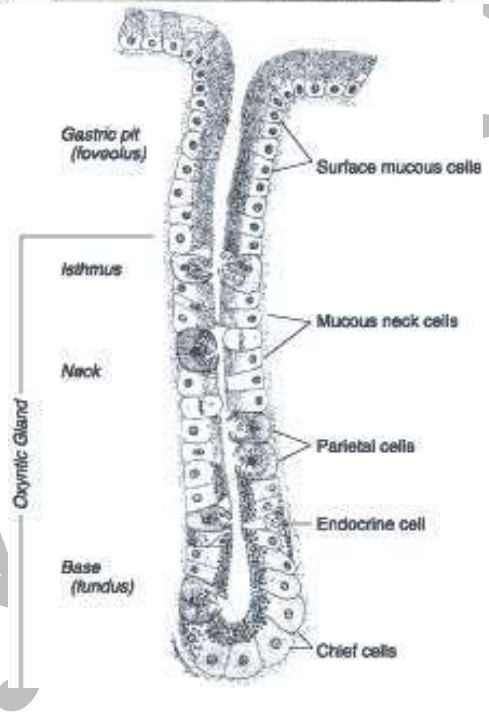
The carbonic acid instantly decomposes into carbon dioxide and water, and then gets eliminated through urine.

Parietal cells (oxyntic cell)	secrete hydrochloric acid (HCL) in very high concentrations
Chief cells	Secreted pepsinogen which is inactive and will digest nothing until it is converted into pepsin when it comes in contact with the hydrochloric acid in the stomach.

HCL performs the following functions:

1. Stomach acid plays role in immune system by killing harmful bacteria and parasite.
2. Stomach acid activates the enzyme pepsin needed for protein digestion.
3. Stomach acid Signals to pancreas produce digestive juice and enzymes to further breakdown food.
4. Stomach acid Initiate ***Peristalsis*** , the rhythmic contraction of the intestine that crush and move the food trough GI tract.
5. Stomach acid is essential for the absorption of vitamin b12 which play key role in the normal functioning of brain and nervous system m in the formation of blood.
6. Reducing food clumps (bolus into smaller particles (chime , so that the intestine can absorb nutrients quickly and effectively.





Lower Gastrointestinal Tract

The lower gastrointestinal tract compromises two primary organs, namely, the intestines or the bowels and the anus. Among the digestive system organs and functions, the organs of the lower gastrointestinal tract help the body to assimilate the nutrients, which have been simplified by the upper gastrointestinal tract.

Small Intestine (Duodenum, Jejunum, Ilium) → Large Intestine (Colon, Cecum, Rectum) → Anus

Small Intestine: is a coiled tube up to 6 meters long and 2-3 cm wide. The small intestine is where final digestion and absorption occur. Coils and folding plus villi give this 3m tube the surface area of a 500-600m long tube. The small intestine is further divided into three parts:

- ***Duodenum /*** is the receiver of simplified food and is connected to the lower section of the stomach. Though, the duodenum is the shortest part of the intestines, a lot of chemical digestion takes place in it. The duodenum is also the place where the digestive juices that are generated by the pancreas and liver mix for further digestion.
- ***Jejunum*** / is the second part of the small intestine .One of the most important functions of this organ is abrogation of nutrients. The jejunum is the mid-section of the smaller intestine and coveys the remainder of the food to the ileum.
- ***Ileum*** / absorbs the nutrients that have been missed by the jejunum. Most of the vitamins are absorbed by the ileum.

Peristalsis / is a radially symmetrical contraction of muscles which propagates in a wave down the muscular tube. In humans, peristalsis is found in the contraction of smooth muscles to propel contents through the digestive tract.

Intestinal enzymes

Intestinal enzymes	
The enzyme	**Function**
Maltase	Breaks down the disaccharide maltose
Lactase (LCT)	Hydrolysis of the disaccharide lactose into constituent galactose and glucose monomers. In humans, lactase is present predominantly along the brush border membrane of the differentiated enterocytes lining the villi of the small intestine. Lactase is essential for digestive hydrolysis of lactose in milk. Deficiency of the enzyme causes lactose intolerance. The optimum temperature for lactase is about 48 °C (118.4 °F) for its activity and has an optimum pH of 6.5.
Sucrase	Is the name given to a number of enzymes that catalyse the hydrolysis of sucrose to fructose and glucose
Trypsin	Is a serine protease found in the digestive system of many vertebrates, where it hydrolyses proteins. Trypsin is secreted into the duodenum, where it acts to hydrolyse peptides into their smaller building blocks, namely amino acids (these peptides are the result of the enzyme pepsin breaking down the proteins in the stomach).
Chymotrypsin (bovine γ chymotrypsin):	Is a digestive enzyme that can perform proteolysis. Chymotrypsin cleaves peptides at the carboxyl side of tyrosine, tryptophan, and phenylalanine because these three amino acids contain aromatic rings, which fit into a 'hydrophobic pocket' in the enzyme. Chymotrypsin is synthesized in the pancreas by protein biosynthesis as a precursor called chymotrypsinogen that is enzymatically inactive.

Most **absorption** occurs in the duodenum and jejunum (second third of the small intestine). The inner surface of the intestine has circular folds that more than triple the surface area for absorption. Villi covered with epithelial cells increase the surface area .The epithelial cells are lined with microvilli that further increase the surface area; a 6 meter long tube has a surface area of 300 square meters. Each villus has a surface that is adjacent to the inside of the small intestinal opening covered in microvilli that form on top of an epithelial cell known as a brush border. Each villus has a capillary network supplied by a small arteriole. Absorbed substances pass through the brush border into the capillary, usually by

passive transport. Maltose, sucrose, and lactose are the main carbohydrates present in the small intestine; they are absorbed by the microvilli. Starch is broken down into two-glucose units (maltose) elsewhere. Enzymes in the cells convert these disaccharides into monosaccharides that then leave the cell and enter the capillary.

Fat digestion is usually completed by the time the food reaches the ileum (lower third) of the small intestine. Bile salts are in turn absorbed in the ileum and are recycled by the liver and gall bladder. Fats pass from the epithelial cells to the small lymph vessel that also runs through the villus.

The three major classes of nutrients that undergo digestion are proteins, lipids (fats) and carbohydrates:

- Proteins and peptides are degraded into amino acids. Chemical breakdown begins in the stomach and continues in the small intestine. Proteolytic enzymes, including trypsin and chymotrypsin, are secreted by the pancreas and cleave proteins into smaller peptides. Carboxypeptidase, which is a pancreatic brush border enzyme, splits one amino acid at a time. Aminopeptidase and dipeptidase free the end amino acid products.
- Lipids (fats) are degraded into fatty acids and glycerol. Pancreatic lipase breaks down triglycerides into free fatty acids and monoglycerides. Pancreatic lipase works with the help of the salts from the bile secreted by the liver and the gall bladder. Bile salts attach to triglycerides to help emulsify them, which aids access by pancreatic lipase. This occurs because the lipase is water-soluble but the fatty triglycerides are hydrophobic and tend to orient towards each other and away from the watery intestinal surroundings. The bile salts are the "middle man" that holds the triglycerides in the watery surroundings until the lipase can break them into the smaller components that are able to enter the villi for absorption.
- Carbohydrates are degraded into simple sugars, or monosaccharides (e.g., glucose). Pancreatic amylase breaks down carbohydrates into oligosaccharides. Brush border enzymes take over from there. The most important brush border enzymes are dextrinase and glucoamylase which further break down oligosaccharides. Other brush border enzymes are maltase, sucrase and lactase.

Brunner glands / (or Pancreal glands or "duodenal glands") are compound tubular submucosal glands found in that portion of the duodenum which is above the sphincter of Oddi. The main function of these glands is to produce a mucus-rich alkaline secretion (containing bicarbonate) in order to: Protect the duodenum from the acidic content of chyme (which is introduced into the duodenum from the stomach); Provide an alkaline condition for the intestinal enzymes to be active, thus enabling absorption to take place; · lubricate the intestinal walls.

Pancreatic juice / is a liquid secreted by the pancreas, which contains a variety of enzymes,(as in the table below) .Pancreatic juice is alkaline in nature due to the high concentration of bicarbonate ions. This is useful in neutralizing the acidic gastric acid, allowing for effective enzymatic action. Pancreatic secretion consists of an aqueous bicarbonate component from the duct cells and enzymatic component from the acinar cells.

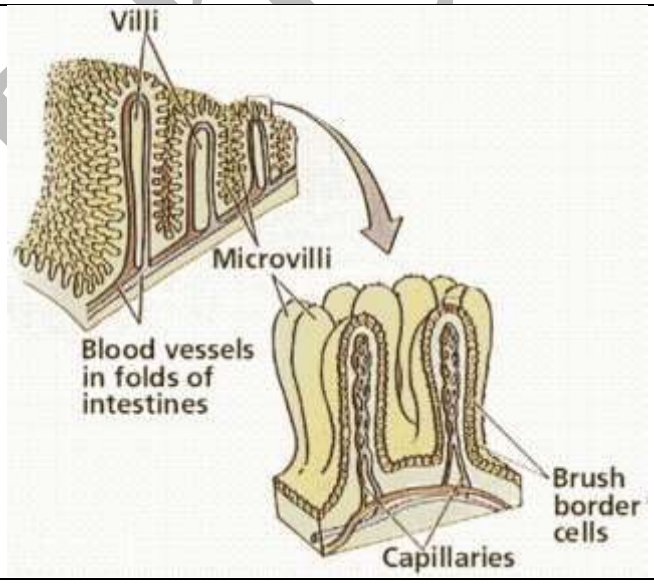
Pancreatic juice components	
The enzyme	**Function**
Trypsinogen	Protein digestion.
Chymotrypsinogen	Conversion of proteins to amino acids.

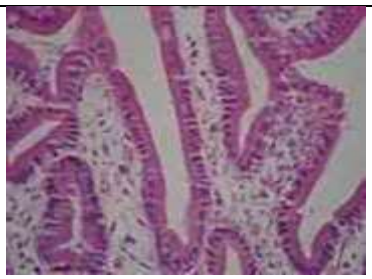
Elastase	An enzyme from the class of *proteases (peptidases)*, that break down proteins. Elastase breaks down elastin, an elastic fiber that, together with collagen, determines the mechanical properties of connective tissue.
Carboxypeptidase	Hydrolyzes the carboxy-terminal (C-terminal) end of a peptide bond. Humans, animals, and plants contain several types of carboxypeptidases with diverse functionsranging from catabolism to protein maturation.
Pancreatic lipase	Uses hydrolysis to break apart fat molecules
amylase	Breaks starch down into sugar is present in human saliva The pancreas also makes amylase (alpha amylase) to hydrolyse dietary starch into di- and trisaccharides

Factors that increase absorption process in the small intestine:

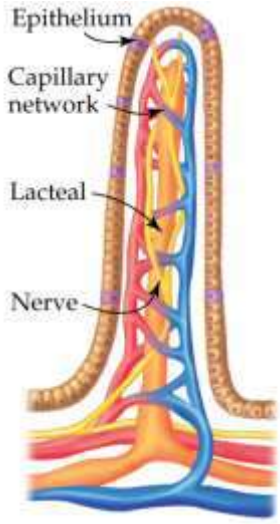
1/ Intestinal Villi (singular: villus) are tiny, finger-like projections that are approximately (0.5-1) mm in length and come out from the wall of the small intestine and have additional extensions called microvilli (singular: microvillus) which protrude from epithelial cells lining villi. They increase the absorptive area and the surface area of the intestinal wall 30-fold, providing exceptionally efficient absorption of nutrients in the lumen. There are also enzymes on the surface for digestion. Villus capillaries collect amino acids and simple sugars taken up by the villi into the blood stream. Villus lacteals (Lymph capillary) collect absorbed chylomicrons, which are lipoproteins composed of triglycerides, cholesterol, and are taken to the rest of the body through the Lymph fluid. Digested nutrients (including sugars and amino acids) pass into the villi through diffusion. Circulating blood then carries these nutrients away.

2/ Intestinal Microvillus (singular: microvillus) are microscopic cellular membrane protrusions that increase the surface area of cells, in humans, microvilli increase intestinal absorptive surface area 600-fold, and are involved in a wide variety of functions, including secretion, cellular adhesion, and mechanotransduction. Thousands of microvilli form a structure called the ***Brush border*** that is found on the apical surface of some epithelial cells, such as the small intestinal enterocyte and the kidney proximal tubule.





Duodenum with Brush border (Microvilli)

	**Villus**

Large Intestine: Like the small intestine, the large intestine is divided into three parts. The first organ of the large intestine is the ***Cecum*****.** The cecum is attached to the ***Appendix*** and is also the connecting pouch between the small and the large intestines. The ***Colon*** comes after the cecum and is responsible for the abrogation of water and salts from the digested foods. This is considered to be the last stage of digestion. The third part of the large intestine is the ***Rectum***, which acts as the connection between the intestines and anus. The large intestine is made up by the colon, cecum, appendix, and rectum. Material in the large intestine is mostly indigestible residue and liquid. Movements are due to involuntary contractions that shuffle contents back and forth and propulsive contractions that move material through the large intestine. Secretions in the large intestine are alkaline mucus that protects epithelial tissues and neutralizes acids produced by bacterial metabolism. Water, salts, and vitamins are absorbed, the remaining contents in the lumen form feces (mostly cellulose, bacteria, bilirubin). Bacteria in the large intestine, such as *E. coli*, produce vitamins (including vitamin K) that are absorbed.

Anus: The anus is among the organs of the digestive system that does the job of ejecting the waste matter from the body.

Auxiliary Organs

The human body has some very important organs in the digestive system which can be classified as the auxiliary organs. Include the following:

Salivary Glands / The salivary glands in mammals are exocrine glands, glands with ducts that produce saliva. They also secrete amylase, an enzyme that breaks down starch into maltose. Most animals have three major pairs of salivary glands that differ in the type of secretion they produce:

- **Parotid glands** produce a serous, watery secretion.
- **Submaxillary (mandibular) glands** produce a mixed serous and mucous secretion.
- **Sublingual glands** secrete saliva that is predominantly mucous in character.

Human saliva is composed of 98% water, while the other 2% consists of other compounds such as electrolytes, mucus, antibacterial compounds, and various enzymes. Its functions include:

1. Moistening food and helping to create a food bolus, so it can be swallowed easily.
2. Saliva contains the enzyme amylase that breaks some cooked starch down into sugar. Thus, digestion of food begins in the mouth.
3. Salivary glands also secrete salivary lipase to start fat digestion.

Gallbladder / The gallbladder is a very important organ that is responsible for the storage of bile that has been produced by the liver. Though, in spite of being an important part of the digestive process, the gallbladder is a non-vital organ, meaning that it is removed in case it gets infected.

Bile or **gall** is a bitter yellowish, blue and green fluid secreted by hepatocytes from the liver of most vertebrates. In many species, bile is stored in the gallbladder between meals and upon eating is discharged into the duodenum where the bile aids the process of digestion of lipids by emulsification. Bile has various components, some of which are produced by hepatocytes in the liver. The main components include:

- Water
- Cholesterol
- Bile pigments (Bilirubin, Biliverdin)
- Bile acids (glycocholic and taurocholic acid)
- Phospholipids (mainly lecithin)
- Bicarbonate that dilutes and increases alkalinity of the solution and other ions

Liver / The liver is one of the most important organs of the human body, as it is also necessary for survival. The liver basically performs the task of producing digestive juices, biochemical and also helps in protein synthesis. The liver is also responsible for detoxification of the food that comes in.

The liver functions in other systems:

- Detoxification of blood
- Synthesis of blood proteins
- Destruction of old erythrocytes and conversion of hemoglobin into a component of bile
- Production of bile
- Storage of glucose as glycogen
- Production of urea from amino groups and ammonia.