Module-3

HUMAN ORGAN SYSTEMS AND BIO DESIGNS

BIOENGINEERING DESIGN

Brain as a CPU system. Eye as a Camera system. Heart as a pump system. Lungs as purification system. Kidney as a filtration system.

BRAIN AS CPU SYSTEM

- The human brain can be thought of as a highly sophisticated and complex information processing system, similar to a computer's Central Processing Unit (CPU). Both the brain and CPU receive and process inputs, store information, and perform calculations to produce outputs.
- However, there are significant differences between the two, such as the way they store and process information and the fact that the human brain has the ability to learn and adapt, while a computer's CPU does not.
- Additionally, the human brain is capable of performing tasks such as perception, thought, and emotion, which are beyond the scope of a computer's CPU.
- In the human brain, information is processed in a distributed manner across multiple regions, each with specialized functions, rather than being processed sequentially in a single centralized location.
- Brain architecture is comprised of billions of connections between individual neurons across different areas of the brain. These connections enable lightning-fast communication among neurons that specialize in different kinds of brain functions.
- Just like how a computer's CPU has an arithmetic logic unit (ALU) to perform mathematical calculations, the human brain has specialized regions for processing mathematical and logical operations. The prefrontal cortex, for example, is responsible for higher-level cognitive functions such as decision making and problem solving.

BASICS FOR COMPARISON	BRAIN	COMPUTER
Construction	Neurons and synapses	ICs, transistors, diode, capacitors, transistors.
Memory growth	Increase each time by connecting synaptic links.	Increases by adding more memory chips.
Information storage	Stored in electrochemical and electric impulses.	Stored in numeric and symbolic form.
Structural organization	Brain is self-organizing self-maintaining and reliable.	Computers perform a monotonous job and can’t correct itself.
Transmission information	Use chemicals to fire the action potential in the neurons.	Communication is achieved through electrical coded signals.

The nervous system has two main parts: The central nervous system is made up of the brain and spinal cord. The peripheral nervous system is made up of nerves that branch off from the spinal cord and extend to all parts of the body.

CNS:

- CNS includes the brain and spinal cord. The brain is the body's "control center." The central nervous system (CNS) is made up of the brain and spinal cord. It is one of 2 parts of the nervous system. The other part is the peripheral nervous system, which consists of nerves that connect the brain and spinal cord to the rest of the body.
- The central nervous system is the body’s processing center. The brain controls most of the functions of the body, including awareness, movement, thinking, speech, and the 5 senses of seeing, hearing, feeling, tasting and smelling.
- The spinal cord is an extension of the brain. It carries messages to and from the brain via the network of peripheral nerves connected to it.
- Nerves also connect the spinal cord to a part of the brain called the brainstem.
- The nervous system is made up of basic units called neurons.
- The neurons are arranged in networks that carry electrical or chemical messages to and from the brain.
- The brain and spinal cord are protected from damage by a clear liquid called cerebrospinal fluid, 3 layers of membranes called the meninges, and the hard bones of the skull and backbone.
- The brain is made up of different parts. These include the cerebrum, the cerebellum, the thalamus, the hypothalamus and the brainstem.
- The cerebrum is the largest part of the brain. It controls intelligence, memory, personality, emotion, speech, and ability to feel and move. It is divided into left and right hemispheres, linked by a band of nerve fibers in the center of the brain called the corpus callosum.

PNS:

- The peripheral nervous system includes all of the nerves that branch out from the brain and spinal cord and extend to other parts of the body, including muscles and organs.
- The primary role of the PNS is to connect the CNS to the organs, limbs, and skin. The nerves of the PNS extend from the central nervous system to the outermost areas of the body.
- The peripheral system allows the brain and spinal cord to receive and send information to other areas of the body, which allows us to react to stimuli.
- The PNS is then subdivided into the autonomic nervous system and the somatic nervous system.

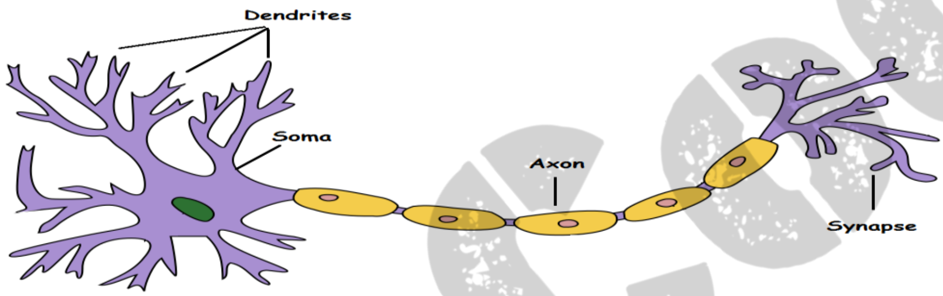
- The autonomic has involuntary control of internal organs, blood vessels, smooth and cardiac muscles.
- The somatic has voluntary control of skin, bones, joints, and skeletal muscle. The two systems function together, by way of nerves from the PNS entering and becoming part of the CNS, and vice versa.
- The somatic system is responsible for transmitting sensory information as well as for controlling voluntary movement. This system contains two major types of neurons:
- **Motor neurons:** Also called efferent neurons, motor neurons carry information from the brain and spinal cord to muscle fibers throughout the body. These motor neurons allow us to take physical action in response to stimuli in the environment.
- **Sensory neurons**: Also called afferent neurons, sensory neurons carry information from the nerves to the central nervous system. The sensory neurons allow us to take in sensory information and send it to the brain and spinal cord.
- The autonomic system is further divided into two branches:
- **Sympathetic system**: By regulating the flight-or-fight response, the sympathetic system prepares the body to expend energy to respond to environmental threats. When action is needed, the sympathetic system triggers a response by accelerating heart rate, increasing breathing rate, boosting blood flow to muscles, activating sweat secretion, and dilating the pupils.
- **Parasympathetic system**: This helps maintain normal body functions and conserve physical resources. Once a threat has passed, this system will slow the heart rate, slow breathing, reduce blood flow to muscles, and constrict the pupils. This allows the body to return to a normal resting state.

SIGNAL TRANSMISSION:

- Electric currents in the vastly complex system of billions of nerves in our body allow us to sense the world, control parts of our body, and think. These are representative of the three major functions of nerves.
- First, nerves carry messages from our sensory organs and others to the central nervous system, consisting of the brain and spinal cord.
- Second, nerves carry messages from the central nervous system to muscles and other organs.
- Third, nerves transmit and process signals within the central nervous system.
- Nerve cells are called as neurons, Signals arrive at the Cell body across synapses or through dendrites, stimulating the neuron to generate its own

signal, sent along its long axon to other nerve or muscle cells.

- A neuron sending a signal (i.e., a presynaptic neuron) releases a chemical called a neurotransmitter, which binds to a receptor on the surface of the receiving (i.e., postsynaptic) neuron. Neurotransmitters are released from presynaptic terminals, which may branch to communicate with several postsynaptic neurons.
- Axon terminals are where neurotransmission begins. Hence, it is at axon terminals where the neuron sends its OUTPUT to other neurons. At electrical synapses, the OUTPUT will be the electrical signal itself. At chemical synapses, the OUTPUT will be neurotransmitter.
- The correct outline for the sequence of transmission of an electrical impulse through a neuron is dendrites, cell body, axon, axon terminal.



ELECTRO ENCEPHALO GRAM[EEG]

- An electroencephalogram (EEG) is a test that measures electrical activity in the brain using small, metal discs (electrodes) attached to the scalp.
- Brain cells communicate via electrical impulses and are active all the time, even during asleep.
- This activity shows up as wavy lines on an EEG recording.
- An EEG is one of the main diagnostic tests for epilepsy. An EEG can also play a role in diagnosing other brain disorders.
- An EEG can find changes in brain activity that might be useful in diagnosing brain disorders, especially epilepsy or another seizure disorder.
- An EEG might also be helpful for diagnosing or treating:
  - Brain tumors
  - Brain damage from head injury
  - Brain dysfunction that can have a variety of causes (encephalopathy)
  - Sleep disorders

- ❖ Inflammation of the brain (herpes encephalitis)
  - ❖ Stroke
- EEG can detect abnormal electrical discharges such as sharp waves, spikes or spike-and-wave complexes that are seen in people with epilepsy, thus it is often used to inform the medical diagnosis.
- EEG can detect the onset and spatio-temporal evolution of seizures and the presence of status epileptics.
- It is also used to help diagnose sleep disorders, depth of anesthesia, coma, encephalopathies, cerebral hypoxia after cardiac arrest, and brain death.
- EEG used to be a first- line method of diagnosis for tumors, stroke and other focal brain disorders, but this use has decreased with the advent of high-resolution anatomical imaging techniques such as magnetic resonance imaging (MRI) and computed tomography (CT).
- Despite limited spatial resolution, EEG continues to be a valuable tool for research and diagnosis.

ROBOTIC ARMS FOR PROSTHETICS:

- Robotic prosthetic limb is a well-established research area that integrates advanced mechatronics, intelligent sensing, and control for achieving higher order lost sensorimotor functions while maintaining the physical appearance of amputated limb.
- Robotic prosthetic limbs are expected to replace the missing limbs of an amputee restoring the lost functions and providing aesthetic appearance.
- The main aspects are enhanced social interaction, comfortable amputee's life, and productive ampute to the society.
- With the advancement of sensor technology, in the last few decades significant contributions have been made in this area.
- If an arm or leg is missing, an artificial limb can sometimes replace it. The device, which is called a prosthesis, can help you to perform daily activities such as walking, eating, or dressing.
- Robotic arms can be used to automate the process of placing goods or products onto pallets. By automating the process, palletizing becomes more accurate, cost-effective, and predictable. The use of robotic arms also frees human workers from performing tasks that present a risk of bodily injury.

ENGINEERING SOLUTIONS FOR PARKINSONS DISEASE

- Parkinson's disease is a progressive disorder that affects the nervous system and the parts of the body controlled by the nerves.
- Symptoms start slowly. The first symptom may be a barely noticeable tremor in just one hand. Tremors are common, but the disorder may also cause stiffness or slowing of movement.
- In Parkinson's disease, certain nerve cells (neurons) in the brain gradually break down or die. Many of the symptoms are due to a loss of neurons that produce a chemical messenger in your brain called dopamine.
- When dopamine levels decrease, it causes a typical brain activity, leading to impaired movement and other symptoms of Parkinson's disease.
- Parkinson's disease can't be cured, but medications can help control the symptoms, often dramatically. In some more advanced cases, surgery may be advised.

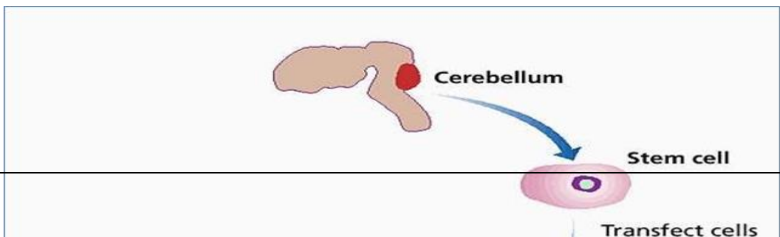
ENGINEERING SOLUTIONS TO THIS DISEASE ARE:

Deep Brain Stimulation - Deep Brain Stimulation (DBS) involves surgically implanting a neurotransmitter that sends electrical impulses to specific areas of your brain.

- This procedure has helped many people with Parkinson's reduce symptoms such as tremor, rigidity, and bradykinesia.
- There are six main types of medications available to treat symptoms of Parkinson disease: levodopa, dopamine agonists, and inhibitors of enzymes that inactivate dopamine inhibitors and catechol-O-methyl transferase [COMT] inhibitors, anticholinergic drugs, and amantadine.

ENGINEERING NEURONS are another treatment method for this.

- Transplantation of embryonic neurons can restore functional dopaminergic neurons in the brains of patients with Parkinson's disease. But while promising, cell transplantation therapy is still out of reach to most patients, in part because of the inaccessibility of human embryonic tissue.
- First obtained neuronal stem cells from mouse cells transfected with a transcription factor that encourages cells to adopt a neuronal fate. They then co-cultured the cells with astrocytes, which release a factor that induces development into dopaminergic neurons. The engineered cells released dopamine, and some maintained the characteristics of dopaminergic neurons for up to two up to two weeks after implantation into mouse brains.

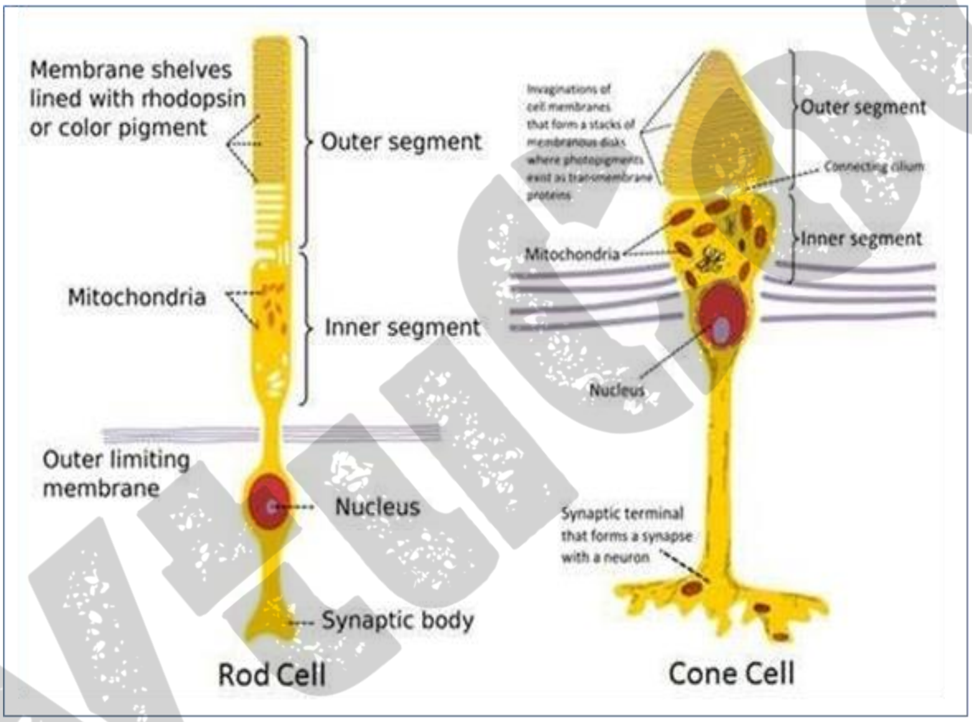


EYE AS A CAMERA SYSTEM:

- The human eye is a wonderful instrument, relying on refraction and lenses to form images. There are many similarities between the human eye and a camera, including:
- A diaphragm to control the amount of light that gets through to the lens. This is the shutter in a camera, and the pupil, at the center of the iris, in the human eye.
- A lens to focus the light and create an image. The image is real and inverted. A method of sensing the image.
- In a camera, film is used to record the image; in the eye, the image is focused on the retina, and a system of rods and cones is the front end of an image-processing system that converts the image to electrical impulses and sends the information along the optic nerve to the brain.
- There are two photoreceptors: RODS AND CONES
- These photoreceptors are localized around an area near the centre of the retina called the macula, which is the functional center of the retina. The fovea is located in the center of the macula. The macula is responsible for high-resolution, color vision, provided by different types of photoreceptors.
- Photoreceptors in the retina are classified into two groups, named after their physical morphologies. Rod cells are highly sensitive to light and function in night vision, whereas cone cells are capable of detecting a wide spectrum of light photons and are responsible for colour vision.
- Rods and cones are structurally compartmentalized. They consist of five principal regions: Outer segment, connecting cilium, Inner segment,

nuclear region, Synaptic region, Rods are responsible for vision at low light levels (scotopic vision). They do not mediate color vision and have a low spatial acuity.

- Cones are active at higher light levels (photopic vision), are capable of color vision and are responsible for high spatial acuity. The central fovea is populated exclusively by cones.
- There are3 types of cones which we will refer to as the short-wavelength sensitive cones, the middle- wavelength sensitive cones and the long-wavelength sensitive cones or S-cone, M-cones, and L- cones.



OPTICAL CORRECTIONS:

- The ability to see images or objects with clear, sharp vision results from light entering the eye. Light rays bend or refract when they hit the retina, sending nerve signals to the optic nerve, which then sends these signals to the brain. The brain processes them into images, allowing you to understand what you see. When these light rays bend incorrectly, it results in a refractive error and typically causes blurry or cloudy vision.

- Eyeglasses and contact lenses – the most common types of corrective measures – are almost always recommended as the first course of treatment for vision problems.

CATARACT

- A cataract is a clouding of the normally clear lens of the eye. At first, the cloudiness in your vision caused by a cataract may affect only a small part of the eye's lens and you may be unaware of any vision loss.
- As the cataract grows larger, it clouds more of your lens and distorts the light passing through the lens. This may lead to more-noticeable symptoms. A cataract is a cloudy lens.
- The lens is positioned behind the colored part of your eye (iris). The lens focuses light that passes into your eye, producing clear, sharp images on the retina — the light-sensitive membrane in the eye that functions like the film in a camera.
- As you age, the lenses in your eyes become less flexible, less transparent and thicker. Age-related and other medical conditions cause proteins and fibers within the lenses to break down and clump together, clouding the lenses.
- As the cataract continues to develop, the clouding becomes denser. A cataract scatters and blocks the light as it passes through the lens, preventing a sharply defined image from reaching your retina.
- As a result, your vision becomes blurred. Cataracts generally develop in both eyes, but not always at the same rate. The cataract in one eye may be more advanced than the other, causing a difference in vision between eyes.
- Cataracts may be partial or complete, stationary or progressive, hard or soft. Histologically, the main types of age-related cataracts are nuclear sclerosis, cortical, and posterior subcapsular.
- Nuclear sclerosis is the most common type of cataract, and involves the central or 'nuclear' part of the lens. This eventually becomes hard, or 'sclerotic', due to condensation on the lens nucleus and the deposition of brown pigment within the lens.
- In its advanced stages, it is called a brunescent cataract. In early stages, an increase in sclerosis may cause an increase in refractive index of the lens.
- Cortical cataracts are due to the lens cortex (outer layer) becoming opaque. They occur when changes in the fluid contained in the periphery

of the lens causes fissuring. Symptoms often include problems with glare and light scatter at night.

- Posterior subcapsular cataracts are cloudy at the back of the lens adjacent to the capsule (or bag) in which the lens sits. Because light becomes more focused toward the back of the lens, they can cause disproportionate symptoms for their size.
- An immature cataract has some transparent protein, but with a mature cataract, all the lens proteinis opaque.
- In a hypermature or Morgagnian cataract, the lens proteins have become liquid.
- Congenital cataract, which may be detected in adulthood, has a different classification and includes lamellar, polar, and sutural cataracts.

LENS MATERIALS:

- Corrective spherocylindrical lenses are commonly used to treat refractive errors such as myopia, hyperopia, presbyopia, and astigmatism.
- Eyeglasses also serve an important role in protecting the eyes from physical trauma and harmful radiation. Lenses can be produced using a variety of materials and designed with several optical profiles to optimize use in specific applications.

  Types of lens materials:

  1.**CR-39**: The most used plastic lens material for years was CR-39. It was first developed as a replacement for glass lenses during World War II. It still has 55% of world market at age 60. Advantages include light weight, good optical properties, and tinting well. Disadvantages of CR-39 are that it is the thickest material and scratches easily.

  2.**Crown Glass** is the most commonly used clear glass for ophthalmic lenses. In general, glass is the most durable material used for lenses. Crown glass is used mainly for single vision lenses and the distance carrier for most glass bifocals and trifocals. It has an index of refraction of 1.523, and an Abbe value of 59. It is approximately 4% thinner than CR-39 resin lenses and is 40% heavier than polycarbonate lenses and is slightly lighter than high index glass. It blocks out about 10% of UV light.

  3.Flint Glass uses lead oxides in its chemical make up to increase its index of refraction to approximately 1.58 to 1.69. Its Abbe value ranges from 30 to 40. This material is relatively soft, displays a brilliant luster and has chromatic aberration.

The advantages of glass lenses include optical clarity, resistance to scratches, and it is the least susceptible to chemicals. The disadvantages include that it is the heaviest material and it is less impact resistant than other materials.

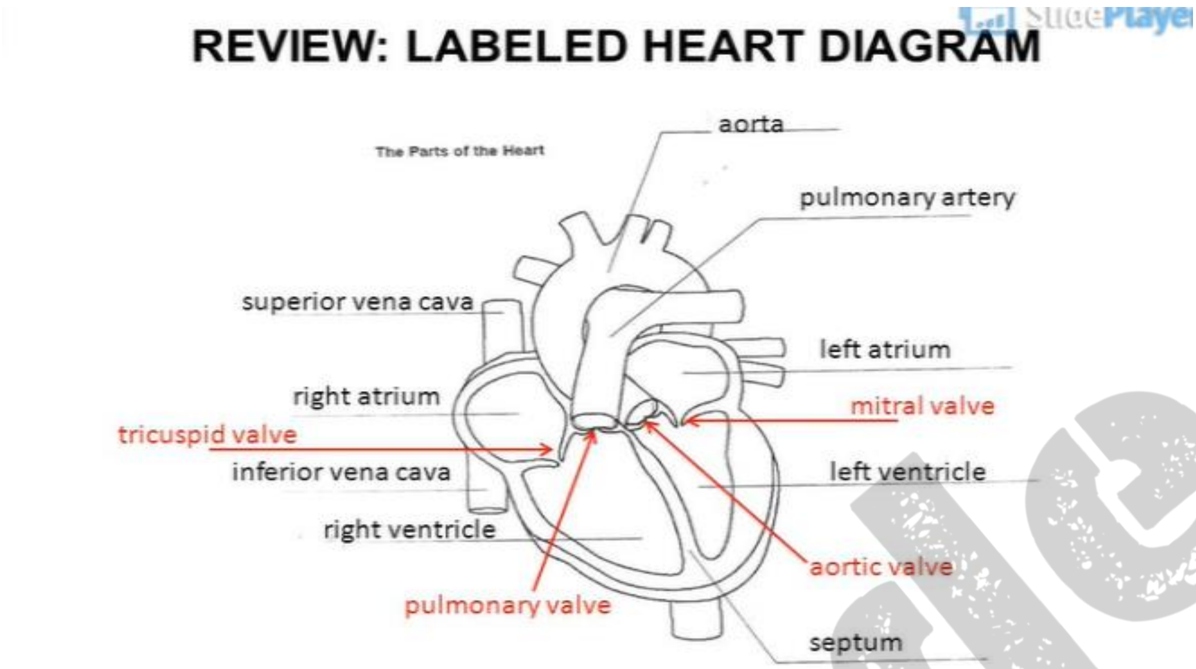
4.Polycarbonate Lenses: Polycarbonate lenses were first developed by a company named Gentex. Polycarbonate is a thermoplastic which means it is moldable under sufficient heat. In the1950's it was marketed under the name Lexan and due to its extraordinary resistance to impact was originally manufactured for safety devices.

BIONIC EYES:

- Bionic eye, electrical prosthesis surgically implanted into a human eye in order to allow for the transduction of light (the change of light from the environment into impulses the brain can process) in people who have sustained severe damage to the retina.
- The bionic eye comprises an external camera and transmitter and an internal microchip. The camera is mounted on a pair of eyeglasses, where it serves to organize the visual stimuli of the environment before emitting high-frequency radio waves
- The stimulator microchip consists of an electrode array that is surgically implanted into the retina. That functions as an electrical relay in place of degenerated retinal cells.
- The radio waves that are emitted by the external camera and transmitter are received by the stimulator, which then fires electrical impulses. The impulses are relayed by the few remaining retinal cells and are transduced as normal to the optic nerve pathway, resulting in vision.
- The bionic vision system consists of a camera, attached to a pair of glasses, which transmits high- frequency radio signals to a microchip implanted in the retina.
- Electrodes on the implanted chip convert these signals into electrical impulses to stimulate cells in the retina that connect to the optic nerve. It is an expensive treatment and not everyone can afford it
- It's an artificial eye which provide visual sensations to the brain. It consist of electronic systems having image sensors, microprocessors, receivers, radio transmitters and retinal chips. Technology provided by this help the blind people to get vision again.

HEART AS A PUMP SYSTEM:

- Heart is sort of like a pump, or two pumps in one. The right side of your heart receives blood from the body and pumps it to the lungs. The left side of the heart does the exact opposite: It receives blood from the lungs and pumps it out to the body.
- The human heart is very strong and is capable of pumping blood up to 30 feet distance. An average heart beats maximum of 70-80 beats per minute and is considered healthy. The efficiency of the heart can be maintained and improved by performing physical activity.
- The heart is called a double pump because each side pumps blood to a different circulation. Deoxygenated blood from the body drains to the right side of the heart. This is the first pump that sends blood to the lungs, called the pulmonary circulation, where it becomes oxygenated and releases carbon dioxide.
- The blood first enters the right atrium. The blood then flows through the tricuspid valve into the right ventricle. When the heart beats, the ventricle pushes blood through the pulmonic valve into the pulmonary artery. The pulmonary artery carries blood to the lungs where it "picks up" oxygen.
- It then leaves the lungs to return to the heart through the pulmonary vein. The blood enters the left atrium. It drops through the mitral valve into the left ventricle. The left ventricle then pumps blood through the aortic valve and into the aorta.
- The aorta is the artery that feeds the rest of the body through a system of blood vessels.
- Blood returns to the heart from the body via two large blood vessels called the superior vena cava and the inferior vena cava. This blood carries little oxygen, as it is returning from the body where oxygen was used. The vena cava pump blood into the right atrium and the cycle begins all over again.



- The human heart is a four-chambered muscular organ, shaped and sized roughly like a man's closed fist with two-thirds of the mass to the left of midline.
- The heart is enclosed in a pericardial sac that is lined with the parietal layers of a serous membrane. The visceral layer of the serous membrane forms the epicardium.
- The myocardium of the heart wall is a working muscle that needs a continuous supply of oxygen and nutrients to function efficiently. For this reason, cardiac muscle has an extensive network of blood vessels to bring oxygen to the contracting cells and to remove waste products.

ELECTRICAL SIGNALING ECG MONITORING :

- The heart's pumping action is controlled by electrical signaling, which generates the rhythm of the heartbeat. This electrical signaling can be monitored using an electrocardiogram (ECG), which records the electrical activity of the heart and provides important information about the heart's function.
- An ECG measures the electrical signals produced by the heart as it beats and generates a trace or waveform that reflects the electrical activity of the heart. This trace can be used to diagnose heart conditions and monitor the heart's function.
- Some common heart-related issues that can be diagnosed or monitored using an ECG include:
- Arrhythmias: Abnormalities in the heart's rhythm or rate can be detected using an ECG

- Heart disease: Changes in the heart's electrical activity can indicate the presence of heart disease, such as coronary artery disease or heart attacks.
- The ECG is a well-established, quick, and easily accessible method for diagnosis and screening of various cardiovascular diseases. It provides specific features that indicate presence of HF or prognosis in HF patients especially to rule out HF in case of a normal ECG. However, use of an ECG as primary diagnostic instrument often only yields insufficient diagnostic specificity.

<u>REASONS FOR BLOCKAGES OF BLOOD VESSELS</u>:

- Coronary artery disease is a common heart condition. The major blood vessels that supply the heart (coronary arteries) struggle to send enough blood, oxygen and nutrients to the heart muscle. Cholesterol deposits (plaques) in the heart arteries and inflammation are usually the cause of coronary artery disease.
- Signs and symptoms of coronary artery disease occur when the heart doesn't get enough oxygen- rich blood. If you have coronary artery disease, reduced blood flow to the heart can cause chest pain (angina) and shortness of breath. A complete blockage of blood flow can cause a heart attack. Coronary artery disease starts when fats, cholesterols and other substances collect on the inner walls of the heart arteries. This condition is called atherosclerosis. The buildup is called plaque. Plaque can cause the arteries to narrow, blocking blood flow. The plaque can also burst, leading to a blood clot.
- Besides high cholesterol, damage to the coronary arteries may be caused by: Diabetes or insulin resistance, High blood pressure, Not getting enough exercise (sedentary lifestyle), Smoking or tobacco use.

<u>DESIGN OF STENTS</u>:

- A stent is a tiny tube that can play a big role in treating your heart disease. It helps keep your arteries-- the blood vessels that carry blood from your heart to other parts of your body, including the heart muscle itself -- open.
- Most stents are made out of wire mesh and are permanent. Some are made out of fabric. These are called stent grafts and are often used for larger arteries.
- Others are made of a material that dissolves and that your body absorbs over time. They're coated in medicine that slowly releases into your artery to prevent it from being blocked again.

DESIGN:

- Most of these stents are constructed from a nickel titanium alloy. Balloon expandable stents are susceptible to permanent deformation when they are compressed extrinsically, which is not an issue in the coronary tree.
- Self-expanding stents do not have this limitation. Furthermore, self-expanding stents have less axial stiffness and are thus more flexible and will conform to the shape of the vessel rather than the vessel conforming to the shape of the stent.
- Balloon expandable stents, by virtue of their design, resist expansion by the balloon, but they have less acute recoil when they are placed in a poorly compliant lesion. However, after the initial deployment, the stent is at its maximal diameter and cannot get larger, whereas a self-expanding stent that is appropriately oversized for the vessel will exhibit a chronic outward force on the lesion and may lead to a larger lumen over time.

PACE MAKERS:

- A pacemaker is a small device that's placed (implanted) in the chest to help control the heartbeat. It's used to prevent the heart from beating too slowly. Implanting a pacemaker in the chest requires a surgical procedure. A pacemaker is also called a cardiac pacing device.
- Types: Single chamber pacemaker. This type usually carries electrical impulses to the right ventricle of your heart.
- Dual chamber pacemaker. This type carries electrical impulses to the right ventricle and the right atrium of your heart to help control the timing of contractions between the two chambers.
- Biventricular pacemaker. Biventricular pacing, also called cardiac resynchronization therapy, is for people who have heart failure and heartbeat problems. This type of pacemaker stimulates both of the lower heart chambers (the right and left ventricles) to make the heart beat more efficiently.
- A pacemaker is implanted to help control your heartbeat. A pacemaker may be implanted permanently to correct a chronic slow or irregular heartbeat or to help treat heart failure.
- Pacemakers work only when needed. If your heartbeat is too slow (bradycardia), the pacemaker sends electrical signals to your heart to correct the beat.
- Some newer pacemakers also have sensors that detect body motion or breathing rate and signal the devices to increase heart rate during exercise, as needed.

- A pacemaker has two parts: Pulse generator. This small metal container houses a battery and the electrical circuitry that controls the rate of electrical pulses sent to the heart.
- Leads (electrodes). One to three flexible, insulated wires are each placed in one or more chambers of the heart and deliver the electrical pulses to adjust the heart rate. However, some newer pacemakers don't require leads. These devices, called leadless pacemakers, are implanted directly into the heart muscle.

DEFIBRILLATORS:

- Defibrillators are devices that send an electric pulse or shock to the heart to restore a normal heartbeat. They are used to prevent or correct an arrhythmia, an uneven heartbeat that is too slow or too fast.
- If the heart suddenly stops, defibrillators can also help it beat again. Different types of defibrillators work in different ways. Automated external defibrillators (AEDs), which are now found in many public spaces, are used to save the lives of people experiencing cardiac arrest.

- Other defibrillators can prevent sudden death among people who have a high risk of a life- threatening arrhythmia.
- They include implantable cardioverter defibrillators (ICDs), which are surgically placed inside your body, and wearable cardioverter defibrillators (WCDs), which rest on the body. There are three types of defibrillators: AEDs, ICDs, and WCDs.
- An AED is a lightweight, battery-operated, portable device that checks the heart's rhythm and sends a shock to the heart to restore normal rhythm. The device is used to help people having cardiac arrest. Sticky pads with sensors, called electrodes, are attached to the chest of someone who is having cardiac arrest. The electrodes send information about the person's heart rhythm to a computer in the AED. The computer analyzes the heart rhythm to find out whether an electric shock is needed. If it is needed, the electrodes deliver the shock.
- ICDs are placed through surgery in the chest or stomach area, where the device can check for arrhythmias. Arrhythmias can interrupt the flow of blood from your heart to the rest of your body or cause your heart to stop. The ICD sends a shock to restore a normal heart rhythm.
- An ICD can give off a low-energy shock that speeds up or slows down an abnormal heart rate, or a high-energy shock to correct a fast or

irregular heartbeat. If low-energy shocks do not restore your normal heart rhythm, the device may switch to high-energy shocks for defibrillation.

- The ICD can also record the heart's electrical activity and heart rhythms.
- WCDs have sensors that attach to the skin. They are connected by wires to a unit that checks your heart's rhythm and delivers shocks when needed. Like an ICD, the WCD can deliver low- and high- energy shocks. The device has a belt attached to a vest that is worn under your clothes.

Lungs as purification system (architecture, gas exchange mechanisms, spirometry, abnormal lung physiology - COPD, Ventilators, Heart-lung machine). Kidney as a filtration system (architecture, mechanism of filtration, CKD, dialysis systems). Muscular and Skeletal Systems as scaffolds (architecture, mechanisms, bioengineering solutions for muscular dystrophy and osteoporosis).

LUNGS AS A PURIFICATION SYSTEM:

Introduction:

Every cell in your body needs oxygen to live. The air we breathe contains oxygen and other gases. The respiratory system's main job is to move fresh air into our body while removing waste gases. Once in the lungs, oxygen is moved into the bloodstream and carried through your body. At each cell in your body, oxygen is exchanged for a waste gas called carbon dioxide. Your bloodstream then carries this waste gas back to the lungs where it is removed from the bloodstream and then exhaled. Your lungs and the respiratory system automatically perform this vital process, called gas exchange.

In addition to gas exchange, your respiratory system performs other roles important to breathing.

These include:

- Bringing air to the proper body temperature and moisturizing it to the right humidity level.
- Protecting your body from harmful substances. This is done by coughing, sneezing, filtering, or swallowing them.
- Supporting your sense of smell.

Lungs help in the purification of blood. Arteries carry pure oxygenated blood from the heart to other parts of the body. Veins carry impure venous blood back from other parts of the body to the right side of the heart. This impure blood goes to the lungs for purification.

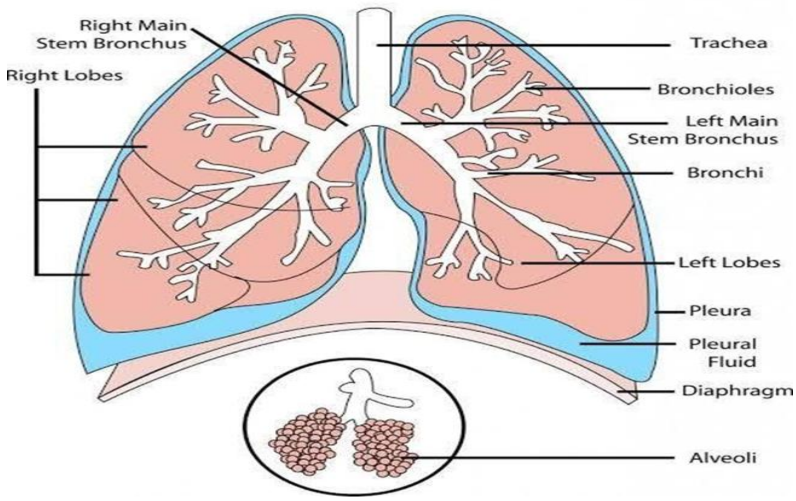
When the breath is inhaled, oxygen from the air comes in contact with the impure blood and the blood takes up oxygen. The waste matter in the blood releases carbonic acid and the blood is purified. The purified blood is carried to the heart by the veins.

Architecture:

- **Trachea:** The trachea is the main airway that leads from the larynx (voice box) to the lungs. It is lined with cilia and mucus-secreting glands that help to filter out harmful substances and trap them in the mucus
- **Bronchi:** The trachea branches into two main bronchi. one for each lung. The bronchi is larger airways that continue to branch into smaller airways called bronchioles.
- **Bronchioles:** The bronchioles are smaller airways that eventually lead to the alveoli which are the sites of gas exchange
- **Alveoli:** The alveoli are tiny air sacs that are lined with a network of capillaries. This close proximity of the alveoli and capillaries allows for efficient diffusion of oxygen and carbon dioxide between the air in the alveoli and the bloodstream.

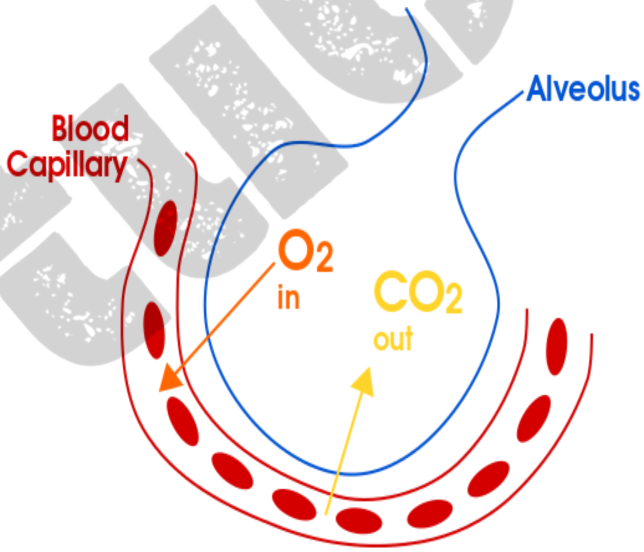
Overall, the architecture of the lung is designed to provide a large surface area for gas exchange, while filtering out harmful substances and humidifying the air. The close proximity of the alveoli and capillaries, along with the moist lining of the respiratory tract, ensures that the air is properly purified and the bloodstream is supplied with fresh, oxygen-rich air.

Diagram of the Human Lungs



GAS EXCHANGE MECHANISMS:

- The gas exchange mechanism in the lung involves the transfer of oxygen from the air in the alveoli to the bloodstream, and the transfer of carbon dioxide from the bloodstream to the air in the alveoli. This process is known as diffusion and occurs due to differences in partial pressures of oxygen and carbon dioxide.
- **Oxygen Diffusion:** The partial pressure of oxygen in the air in the alveoli is higher than the partial pressure of oxygen in the bloodstream. This difference creates a gradient that causes oxygen to diffuse from the alveoli into the bloodstream, where it binds to hemoglobin in red blood cells to form oxyhemoglobin.
- **Carbon Dioxide Diffusion**: The partial pressure of carbon dioxide in the bloodstream is higher than the partial pressure of carbon dioxide in the air in the alveoli. This difference creates a gradient that causes carbon dioxide to diffuse from the bloodstream into the alveoli, where it is exhaled
- During gas exchange oxygen moves from the lungs to the bloodstream. At the same time, carbon dioxide passes from the blood to the lungs. This happens in the lungs between the alveoli and a network of tiny blood vessels called capillaries, which are located in the walls of the alveoli.



SPIROMETRY:

- Spirometry is a diagnostic test that measures the function of the lungs by measuring amount and flow rate of air that can be exhaled.
- The test is commonly used to diagnose lung conditions such as asthma, chronic obstructive pulmonary disease (COPD), and interstitial lung disease.

- **Principle**: The principle behind spirometry is to measure the volume of air that can be exhaled from the lungs in a given time period. By measuring the volume of air exhaled. spirometry can provide information about the functioning of the lungs and the ability of the lungs to move air in and out.
- **Working:** Spirometry is performed using a spirometer, a device that consists of a mouthpiece, a flow sensor, and a volume sensor. The patient is asked to exhale as much air as possible into the spirometer, and the spirometer measures the volume and flow rate of the exhaled air. The volume of air exhaled is displayed on a graph called a flow-volume loop, which provides information about the lung function.

The results of spirometry can be used to determine if the lungs are functioning normally and to diagnose lung conditions. For example, a decrease in the volume of air exhaled or a decrease in the flow rate of the exhaled air can indicate a restriction in the airways, which can be a sign of a lung condition such as asthma or COPD.

COPD

- Chronic Obstructive Pulmonary Disease (COPD) is a group of progressive lung diseases that cause breathing difficulties. It's characterized by persistent airflow limitation that is not fully reversible.
- The two main forms of COPD are **chronic bronchitis** and **emphysema** Symptoms include breathing difficulty, cough, mucus (sputum) production, and wheezing. It's typically caused by long-term exposure to irritating gases or particulate matter, most often from cigarette smoke. People with COPD are at increased risk of developing heart disease, lung cancer, and a variety of other conditions.

Emphysema and chronic bronchitis are the two most common conditions that contribute to COPD These two conditions usually occur together and can vary in severity among individuals with COPD.

Symptoms

Symptoms COPD symptoms often don't appear until significant lung damage has occurred, and they usually worsen over time, particularly if smoking exposure continues.

Signs and symptoms of COPD may include:

Shortness of breath, especially during physical activities

- Wheezing
- Chest tightness
- A chronic cough that may produce mucus (sputum) that may be clear, white, yellow, or greenish
- Frequent respiratory infections
- Lack of energy
- Unintended weight loss (in later stages)
- Swelling in ankles, feet, or legs

Tests may include:

- Lung (pulmonary) function tests.
- Chest X-ray.
- CT scan.
- Arterial blood gas analysis.
- Laboratory tests.

Medications

Several kinds of medications are used to treat the symptoms and complications of COPD few are listed below:

Bronchodilators, Inhaled steroids, Combination inhalers, Oral steroids, Phosphodiesterase-4 inhibitors, Theophylline, Antibiotics.

VENTILATOR:

A ventilator is a device that supports or takes over the breathing process, pumping air into the lungs. Types of ventilator:

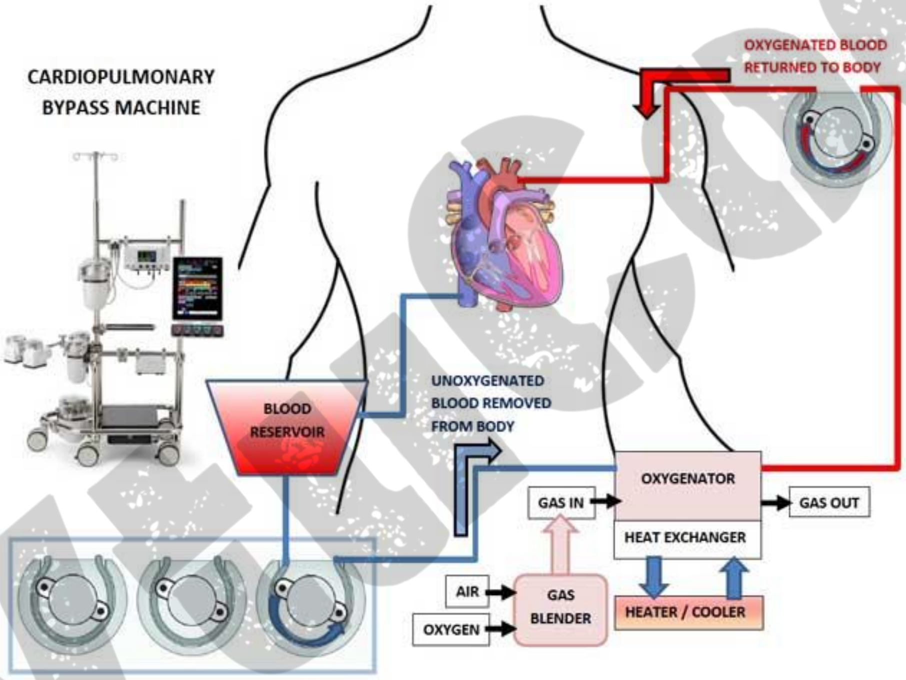
- Face mask ventilators
- Mechanical ventilators
- Manual resuscitator bags
- Tracheostomy ventilators

Ventilators work by delivering pressurized air or oxygen into the lungs through a breathing tube or mask. The pressure can be adjusted to match the patient's needs and to help maintain adequate oxygen levels in the blood.

While ventilators can be lifesaving for individuals with acute respiratory failure.

HEART LUNG MACHINE:

- A heart-lung machine is an apparatus that does the work both of the heart (i.e., pumps blood) and the lungs (i.e., oxygenates the blood) during, for example, open-heart surgery.
- The basic function of the machine is to oxygenate the body's venous supply of blood and then to pump it back into the arterial system.
- Blood returning to the heart is diverted through the machine before returning to the arterial oxygenators, temperature regulators, and filters. The heart-lung machine also provides intracardiac suction, filteration and temperature control.



- Blood drains by gravity or with the use of gentle suction into the oxygenator venous reservoir. Arterial pump that pumps the blood from the venous reservoir and delivers blood to the membrane oxygenator which is attached to the lower part of the venous reservoir.
- Once oxygen, carbon dioxide, and heat exchange have occurred the blood is directed to an arterial blood filter..
- The oxygenated blood is introduced back into the patient's circulatory system through cannulae (a large tube connected to the circuit) placed in the ascending aorta.

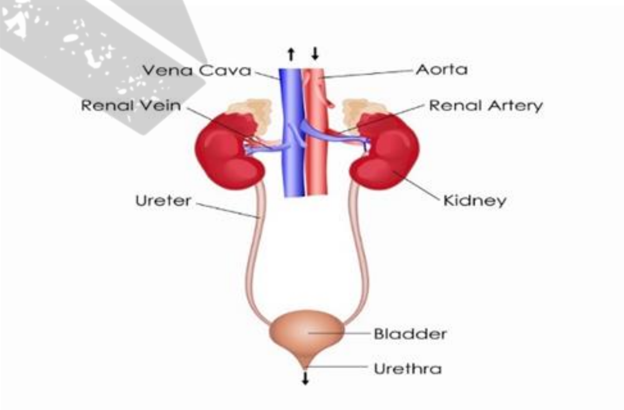
- The one on the far left is used to pump a cardioplegia solution with a mixture of blood and additives, used to arrest the heart.

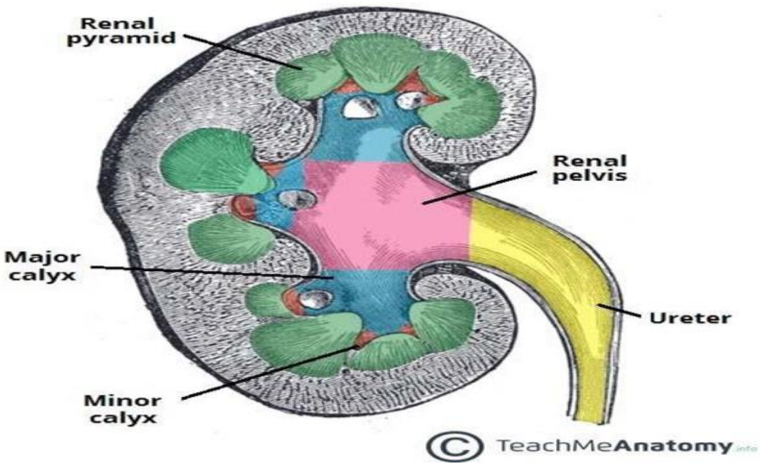
KIDNEY AS FILTRATION SYSTEM:

- Kidneys remove wastes and extra fluid from the body. Kidneys also remove acid that is produced by the cells of the body and maintain a healthy balance of water, salts, and minerals- such as sodium, calcium, phosphorus, and potassium in the blood. Without this balance, nerves, muscles, and other tissues in the body may not work normally.

Architecture:

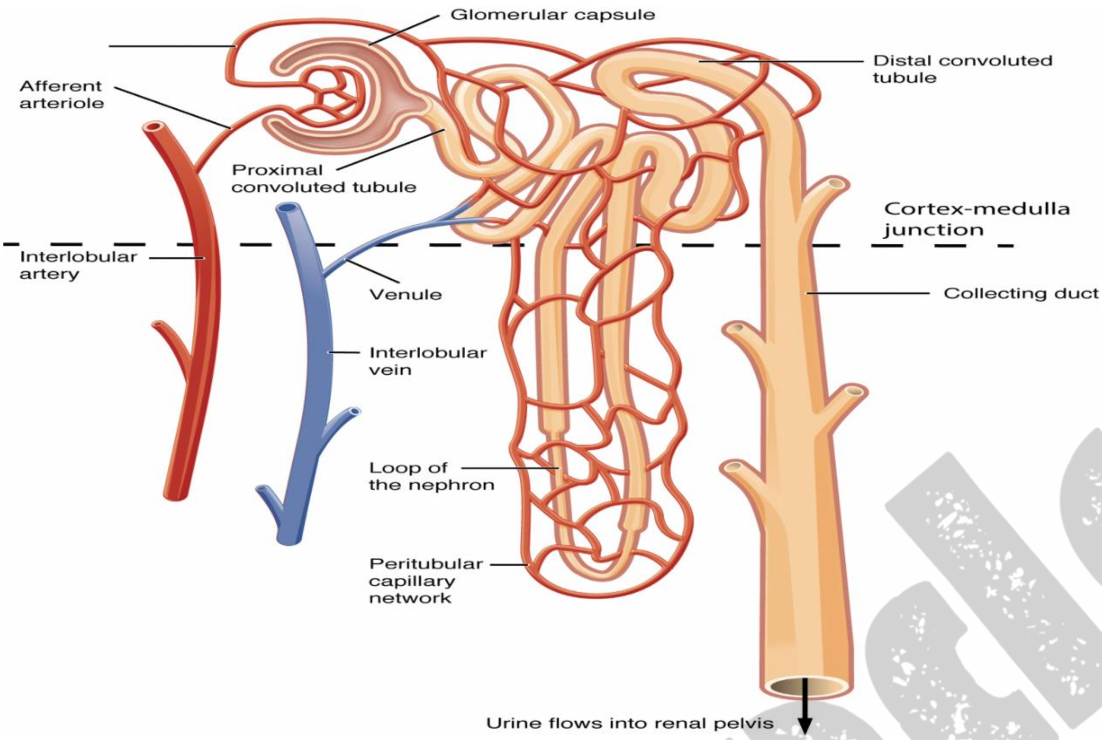
- The kidneys are two bean-shaped organs, each about the size of a fist. They are located just below the rib cage, one on each side of the spine. Healthy kidneys filter about a half cup of blood every minute, removing wastes and extra water to make urine.
- The urine flows from the kidneys to the bladder through two thin tubes of muscles called ureters, one on each side of the bladder. Your bladder stores urine. Kidneys, Ureters, and bladder are part of your urinary tract.
- The renal parenchyma is divided into outer cortex and inner medulla. The cortex extends into the medulla, dividing it into triangular shapes – these are known as renal pyramids.
- The apex of a renal pyramid is called a renal papilla. Each renal papilla is associated with a structure known as the minor calyx, which collects urine from the pyramids. Several minor calices merge to form a major calyx. Urine passes through the major calices into the renal pelvis, a flattened and funnel-shaped structure. From the renal pelvis, urine drains into the ureter, which transports it to the bladder for storage.





MECHANISM OF FILTRATION:

- Each kidney is made up of about a million filtering units called nephrons. Each nephron includes a filter, called the glomerulus, and a tubule.
- The nephrons work through a two-step process: the glomerulus filters blood, and the tubule returns needed substances to your blood and removes wastes.
- Bowmans Capsule- this is a cup shaped structure that surrounds the glomerulus and filters waste and excess fluid from the bloodstream into the renal tube.
- Glomerulus: A network of tiny blood vessels within the Bowman's capsule that filters waste and excess fluid from the bloodstream.
- Proximal convoluted tubule: A segment of the renal tubule that reabsorbs important substances, such as glucose, amino acids, and electrolytes, back into the bloodstream.
- Loop of Henle: A U-shaped segment of the renal tubule that is critical for the reabsorption of ions and water.
- Distal convoluted tubule: A segment of the renal tubule that regulates the levels of electrolytes and other important substances in the bloodstream.
- Collecting duct: A series of ducts that collect the filtrate from the renal tubules and transport it to the renal pelvis, where it drains into the ureter and eventually into the bladder.



The nephrons are surrounded by a network of blood vessels, including the afferent arteriole and the efferent arteriole, which bring blood into and out of the glomerulus, respectively. The filtrate produced by the nephron passes through the renal tubules, where it is modified by reabsorption and secretion, before being eliminated from the body as urine.

URINE FORMATION

- Blood enters the kidney through the renal arteries and flows into tiny filtering units called glomeruli. At the glomerulus, the pressure in the blood vessels causes a portion of the plasma and dissolved substances to filter out and enter a structure called Bowman's capsule.
- In Bowman's capsule, the filtrate is then transferred into the renal tubules, which are the main filtering units of the kidneys.
- In the renal tubules, the filtrate passes through a series of specialized cells, such as proximal tubular cells and distal tubular cells, which reabsorb important substances such as glucose, amino acids, and electrolytes back into the bloodstream.
- At the same time, the renal tubules secrete waste products, such as urea and creatinine, back into the filtrate. Finally, the filtered fluid, now known as urine.

CKD

- Chronic kidney disease includes conditions that damage your kidneys and decrease their ability to keep you healthy by filtering wastes from your blood.
- If kidney disease worsens, wastes can build to high levels in your blood and make you feel sick. You may develop complications like high blood pressure, anemia (low blood count),weak bones, poor nutritional health, nerve damage.

Symptoms:

- People with CKD may not feel ill or notice any symptoms. The only way to find out for sure if you have CKD is through specific blood and urine tests.
- These tests include the measurement of both the creatinine level in the blood and the protein in the urine

Treatment:

Depending on the cause, some types of kidney disease can be treated. Often, though, chronic kidney disease has no cure. Treatment usually consists of measures to help control signs and symptoms, reduce complications, and slow the progression of the disease.

If your kidneys become severely damaged, you might need treatment for end-stage kidney disease.

DIALYSIS:

Dialysis is a procedure to remove waste products and excess fluid from the blood when the kidneys stop working properly. It often involves diverting blood to a machine to be cleaned.

There are 2 main types of dialysis:

- Hemodialysis involves diverting blood into an external machine, where it's filtered before being returned to the body. During hemodialysis. blood is removed from the body, passed through a dialysis machine that filters out waste and excess fluids, and then returned to the body. Haemodialysis typically takes place in a hospital or dialysis centre, and is typically performed three times a week for three to four hours at a time

- Peritoneal dialysis is a type of dialysis that uses the lining of the abdomen, called peritoneum, to filter waste and excess fluids from the blood. A sterile solution is introduced into the abdomen. where it absorbs waste and excess fluids, and is then drained and replaced with fresh solution. Peritoneal dialysis can be performed at home.

Artificial Kidney

- While much progress has been made in developing an artificial kidney, it is still in the experimental stage and is not yet widely available. Further research and development is needed to improve the efficiency and safety of artificial kidney devices, and to ensure that they can be widely adopted as a treatment for chronic kidney disease. There are currently two main approaches to developing an artificial kidney:
- a biological approach and a technological approach. The biological approach involves using living cells, such as kidney cells or stem cells, to create a functional, implantable artificial kidney. The technological approach involves using synthetic materials, such as silicon or polymer, to create a dialysis device that can filter the blood and remove waste and excess fluids.
- It's important to note that while the development of an artificial kidney holds great promise, it is not a cure for chronic kidney disease and patients with kidney failure will still need dialysis or kidney transplantation in the meantime.

QUESTION BANK

L1

1. Define dialysis.
2. What is spirometry?
3. Define ventilators ?
4. Define heart lung machine?
5. What is chronic obstructive pulmonary disease?
6. What is CKD?

L2

1. Explain the architecture of the lungs as a purification system. Discuss the different parts of the respiratory system and their role in filtering harmful substances and facilitating gas exchange.

2. Describe the gas exchange mechanism in the lungs. Discuss the process of oxygen diffusion into the bloodstream and carbon dioxide diffusion out of the bloodstream in the alveoli.
3. Discuss the principle and working of spirometry as a diagnostic test for evaluating lung function. Explain how spirometry results can be interpreted and used in the diagnosis of lung conditions.
4. Explain the concept of abnormal lung physiology, focusing on Chronic Obstructive Pulmonary Disease (COPD) as an example. Discuss the causes, symptoms, and treatment options for COPD.
5. Describe the architecture of the kidney and its functional units, known as nephrons. Discuss the role of each component of the nephron in the filtration, reabsorption, and secretion processes.
6. Explain the mechanism of filtration in the kidneys, including the steps involved in the formation of urine. Discuss the importance of filtration, reabsorption, and secretion in maintaining the balance of fluids and electrolytes in the body.
7. Discuss the concept of Chronic Kidney Disease (CKD), including its causes, symptoms, and potential complications. Describe the treatment options available for managing CKD, emphasizing the importance of regular check-ups and lifestyle modifications.
8. Compare and contrast the two main types of dialysis systems: hemodialysis and peritoneal dialysis.
9. Describe how muscular systems can be used as scaffolds in regenerative medicine. Provide examples of their applications in the treatment of damaged heart tissue and skeletal muscle injuries.
10. Explain the architecture of skeletal muscles, including the organization of muscle fibers, connective tissue layers, and the role of sarcomeres in muscle contraction.
11. Discuss the mechanisms involved in using muscle cells and scaffolds for tissue regeneration in regenerative medicine. Explain the steps involved in growing muscle tissue using hydrogel or artificial scaffold.
12. Explore the bioengineering solutions being developed for muscular dystrophy. Explain how gene therapy, stem cell therapy, exoskeleton technology, and tissue engineering can potentially improve the lives of individuals affected by the disease.
13. Explain hart lung machine with a labelled diagram.

QUESTION BANK

BTL L1 QUESTIONS

1. What are pace makers?
2. What is Parkinsons Disease?
3. Define EEG.
4. What are stents?
5. What are defibrillators?

BTL L2 QUESTIONS

1. "Brain as CPU system" justify the statement.
2. Write short note on CNS.
3. Write short note on PNS.
4. How is signal transmitted within the body.
5. Explain EEG and its diagnostic uses.
6. What are the engineering solutions for Parkinsons disease.
7. How is cataract caused? Explain.
8. Explain how heart acts as a pump system.
9. Explain the different types of lens materials.
10. Write a short note on bionic eyes.
11. What are the reasons for heart blockages? Mention the uses of stents.
12. Explain the types and parts of Pace makers.
13. Write a short note on defibrillators.