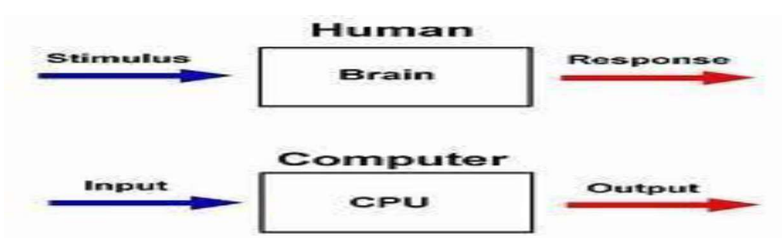
	Module - 2
2.1	**Adaptation of anatomical principles for bioengineering design:** Brain as a CPU system, Eye as a Camera system, Heart as a pump system.
2.2	Lungs as purification system, Kidney as a filtration system.
2.3	**Nature-bioinspired materials and mechanisms:** Echolocation, Photosynthesis, Bird flying, Lotus leaf effect, Plant burrs, Shark skin, Kingfisher beak.
2.4	Human Blood substitutes - haemoglobin-based oxygen carriers (HBOCs) and perfluorocarbons (PFCs).

BRAIN AS A CPU SYSTEM:

Both CPU and brain use electrical signals to send messages. The brain uses chemicals to transmit information; the computer uses electricity. Even though electrical signals travel at high speeds in the nervous system, they travel even faster through the wires in a computer. Both transmit information.

Both the brain and CPU receive and process inputs, store information, and perform calculations to produce outputs. Differences between the two - 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.



BRAIN VS COMPUTER

Term	Brain	Computer
Speed	Execution time is few milliseconds	Execution time is few nano seconds
Processing	Perform massive parallel operations simultaneously	Perform several parallel operations simultaneously. It is faster the biological neuron
Size and complexity	Number of Neuron is 10^{11} and number of interconnections is 10^{15}. So complexity of brain is higher than computer	It depends on the chosen application and network designer.
Storage capacity	i) Information is stored in interconnections or in synapse strength. ii) New information is stored without destroying old one. iii) Sometimes fails to recollect information	i) Stored in continuous memory location. ii) Overloading may destroy older locations. iii) Can be easily retrieved

ATIC 8

Architecture

The human brain as a CPU system can be compared to that of a parallel distributed processing system, as opposed to the Von Neumann architecture of traditional computers.

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.

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. Computer's CPU also has memory units for storing information, and the human brain has several regions dedicated to memory storage, including the hippocampus and amygdala.

CNS and PNS (Central Nervous System and Peripheral Nervous System)

The CNS consists of the brain and spinal cord and is responsible for receiving, processing, and integrating sensory information and transmitting commands to the rest of the body.

Brain- command center, receiving and processing sensory inputs and generating motor outputs, while the spinal cord - a relay center, transmitting information between the brain and peripheral nerves.

The PNS consists of all the nerves that lie outside the brain and spinal cord. It is responsible for transmitting sensory information from the periphery of the body (such as the skin, muscles, and organs) to the CNS, and transmitting commands from the CNS to the periphery.

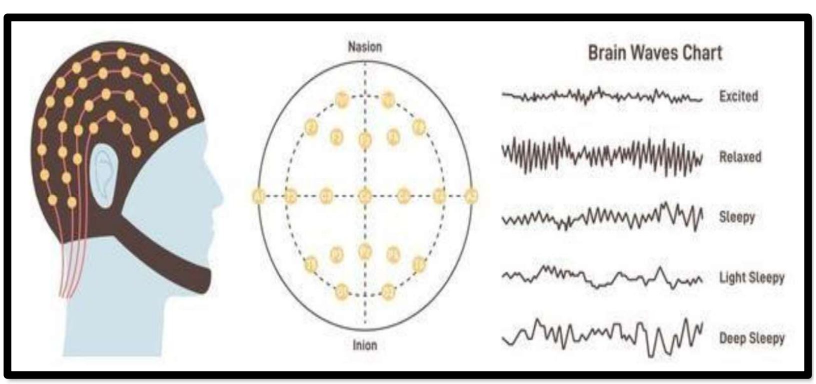
Signal Transmission - through the firing of nerve cells, or neurons.

A neuron **receives inputs** from other neurons at its **dendrites**, integrates the information, and then generates an electrical impulse, or action potential, that **travels down its axon** to the synaptic terminals.

At the **synaptic terminals**, the neuron releases chemical **neurotransmitters**, which cross the synaptic gap and bind to receptors on the postsynaptic neuron, leading to the initiation of another action potential in the postsynaptic neuron.

EEG (electroencephalography)

- Non-invasive method for measuring and recording of the electrical activity of the brain.
- The signals are recorded through electrodes placed on the scalp and the resulting EEG pattern provides information about the synchronized electrical activity of large populations of neurons.



Applications of EEG

Diagnosis of Epilepsy: and **other seizure disorders**. It can detect abnormal electrical activity in the brain - diagnosis and determine the location of the seizure focus.

Sleep Studies: to evaluate sleep patterns and diagnose sleep disorders.

Brain-Computer Interfaces (BCI): EEG can be used to control external devices such as prosthetic limbs or computer software. This is done by detecting specific brain waves associated with a particular mental state, such as concentration or relaxation.

Research on Brain Function: during various activities such as reading, problem-solving, and decision-making. And also be used to investigate how the brain responds to stimuli such as light, sound, and touch.

Diagnosis of Brain Disorders: including dementia, Parkinson's disease, and traumatic brain injury.

Anesthesia Monitoring: during surgery to ensure that the patient remains in a safe and comfortable state.

Monitoring Brain Activity during Coma: to determine the level of brain function and assess the likelihood of recovery.

EEG Signals and Types of Brain Activity

Delta waves (0.5-4 Hz): low-frequency waves associated with deep sleep, infancy, and brain disorders such as brain damage or dementia.

Theta waves (4-8 Hz): associated with sleep and relaxation, as well as meditation and hypnosis. They are present during memory encoding and retrieval processes.

Alpha waves (8-12 Hz): are present when the brain is relaxed and not focused on any particular task. They are associated with meditation and creativity.

Beta waves (12-30 Hz): are present when the brain is focused on a task, such as problem-solving or decision-making. They are associated with anxiety and stress.

Gamma waves (30-100 Hz): are associated with high-level cognitive processing, such as attention, perception, and memory. They are involved in sensory processing and motor control. The analysis of EEG signals can provide valuable information about brain function and activity, as well as offer insights into the workings of the human mind.

Robotic Arms for Prosthetics

The devices that use robotics technology to restore functionality to individuals with upper limb amputations. These devices typically use motors, actuators, and sensors to mimic the movements of a human arm and hand, allowing the wearer to perform tasks such as reaching, grasping, and manipulating objects.

It can be controlled in a variety of ways, including direct control through muscle signals (myoelectric control) or brain-machine interfaces, which use electrodes implanted in the brain or placed on the scalp to detect and interpret brain activity.

Some prosthetic arms also incorporate machine learning algorithms to improve their performance and adapt to the user's needs over time.

Robotic Arm Prosthetic Direct Control through Muscle Signals (myoelectric control)

- It involves using the electrical signals generated by the wearer's remaining muscles to control the movement of the prosthetic.
- The electrodes placed on the skin over the remaining muscle that are used to detect and interpret the electrical signals generated by the muscle contractions.
- When the wearer contracts their muscles, the electrodes detect the electrical signals and send them to a control unit, which interprets the signals and uses them to control the movement of the robotic arm.
- Depending on the specific design, the control unit may use pattern recognition algorithms (movement intending to perform) . or a combination
- of muscle signals (specific degrees of freedom). Myoelectric control has the **advantage** of being **directly controlled by the user**, allowing for a more intuitive and natural interaction with the prosthetic.
- It can also provide a **high level of control and precision**, as the electrical signals generated by the muscles are unique to each individual and can be used to perform a wide range of movements.
- However, myoelectric control systems can be **complex and may require extensive rehabilitation and training** to use effectively, as well as **ongoing maintenance** to

ensure proper function.

- Additionally, the system may not be suitable for individuals with muscle weakness or other conditions that affect the ability to generate strong electrical signals.

Robotic Arm Prosthetic by Brain-Machine Interfaces (BMIs)

- Brain-machine interfaces are a type of technology that allows a user to control a robotic arm prosthetic directly with their brain activity.
- The system typically involves electrodes placed on the scalp or implanted directly into the brain to detect and interpret the user's brain signals.
- When the user thinks about moving the prosthetic arm, the electrodes detect the corresponding brain activity and send the signals to a control unit, which uses algorithms to interpret the signals and control the movement of the prosthetic.
- The user can then control the movement of the prosthetic in real-time by thinking about the desired movement.
- BMIs have the **advantage** of providing a **direct and intuitive connection** between the user's brain and the prosthetic, allowing for a high level of control and precision.
- BMIs can be **used to provide sensory feedback to the user**, allowing them to experience the sensation of touch through the prosthetic.

- BMIs can be **complex** and **invasive systems**, requiring surgical implantation and ongoing maintenance to ensure proper function.
- They may not be suitable for individuals with conditions that affect brain activity or who are unable to generate strong enough brain signals to control the prosthetic effectively.

Engineering Solutions for Parkinson's Disease

Parkinson's disease is a neurodegenerative disorder that affects movement and motor function.

Deep Brain Stimulation (DBS): involves the implantation of electrodes into specific regions of the brain to deliver electrical stimulation - help to relieve symptoms like tremors, stiffness, and difficulty with movement.

Exoskeletons: are wearable devices that provide support and assistance for individuals with mobility issues and help to improve balance, reduce tremors, and increase overall mobility.

Telerehabilitation: involves the use of telecommunication technology to provide physical therapy and rehabilitation services without the need for in-person visits to a therapist. **Smart watch Applications**: to monitor symptoms of Parkinson's disease, such as tremors, and provide reminders and prompts for medication and exercise.

Virtual Reality: is a system used for rehabilitation and therapy, providing interactive and engaging environments for patients to practice movements and improve coordination and balance.

These engineering solutions have the potential to significantly improve the quality of life for individuals with Parkinson's disease.

Artificial Brain or artificial general intelligence (AGI) or a synthetic brain

It is a hypothetical machine that could possess cognitive abilities similar to those of a human brain. The idea behind artificial brains is to create a machine that can learn, reason, and solve problems in the same way that humans do.

However, the development of artificial brains is still in the early stages and there are many technical, ethical, and philosophical challenges that need to be addressed. Currently, artificial intelligence (AI) systems are designed to perform specific tasks, such as image recognition, speech recognition, or decision making, but they are not capable of general intelligence

This is because AI systems are designed to operate within a narrow domain and lack the ability to learn from new experiences, generalize from past experiences, or reason about the world in the same way that humans do.

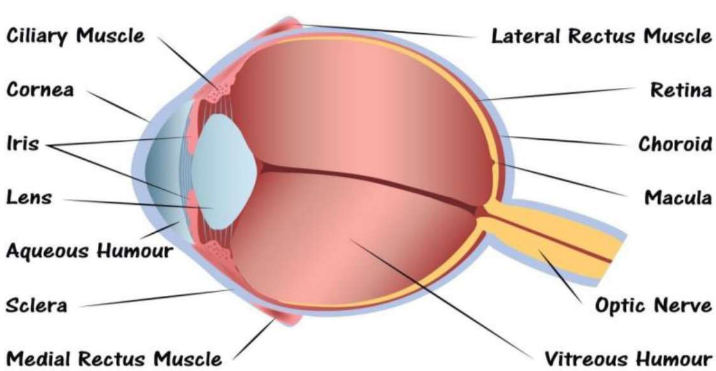
The development of artificial brains requires a deep understanding of the human brain and its functions, as well as advanced computer science and engineering skills.

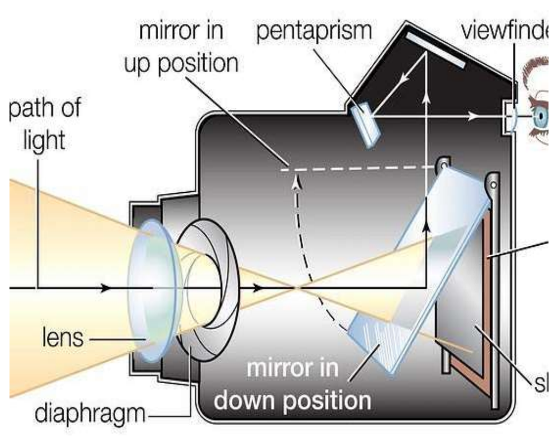
EYE AS A CAMERA SYSTEM

The human eye can be analogized to a camera system, as both the eye and a camera capture light and convert it into an image.

The main components of the eye that correspond to a camera system include:

- The **Cornea**: This transparent outer layer of the eye functions like a **camera lens**, bending light to focus it onto the retina.
- The **Iris**: The iris functions like the **diaphragm** in a camera, controlling the amount of light that enters the eye.
- The **Pupil**: The pupil functions like the **aperture** in a camera, adjusting the size to control the amount of light entering the eye.
- Retina: The retina functions like the camera film sensor, capturing the light and converting it into electrical signals that are sent to the brain.
- The **Optic Nerve**: The optic nerve functions like the **cable connecting** the camera to a computer, transmitting the electrical signals from the retina to the brain.





In both the eye and a camera, the captured light is transformed into an image by the lens and the light-sensitive component.

The eye processes the image further, allowing for visual perception, while a camera stores the image for later use.

The eye is much more complex than a camera and has several additional functions, such as adjusting for different levels of light and adjusting focus, that are not found in a camera.

The eye also has the ability to perceive depth and color, as well as adjust

- **Rod Cells** are photoreceptor cells in the **retina** of the eye that are responsible for detecting light and transmitting signals to the brain for the perception of vision, especially in low light conditions.

- **Cone Cells** are photoreceptor cells in the retina of the eye that are responsible for color vision and visual acuity (sharpness of vision).

Bionic Eye or Artificial Eye / retinal implant

Is a type of prosthetic device that is surgically implanted into the eye to help restore vision to people who have lost their sight due to certain conditions such as retinitis pigmentosa or age-related macular degeneration.

The device typically consists of a camera, a processor, and an electrode array that is attached to the retina.

The camera captures images and sends signals to the processor, which then transmits electrical stimulation to the electrodes in the retina to stimulate the remaining healthy cells and restore vision.

The restored vision is not perfect, but it can help people with vision loss to perform daily tasks more easily and safely.

Materials Used in Bionic Eye

The materials used in a bionic eye can vary depending on the specific device and manufacturer.

Silicon or other **semiconducting materials** for the camera and the electrode array.

Biocompatible materials for the casing of the device and the electrode array, such as titanium or titanium alloys, to minimize the risk of infection and rejection by the body.

Conductive materials, such as platinum, iridium, or gold, for the electrodes in the array to provide efficient electrical stimulation to the retina.

Polymers, such as silicone or polyimide, for insulation and protection of the electrodes and other components.

Optical materials, such as glass or acrylic, for the lens of the camera.

Biocompatible and flexible materials for the electrical connections between the camera and the processing unit and between the processing unit and the electrode array.

In addition to these materials, advanced computer algorithms and machine learning techniques are also used to improve the accuracy and reliability of the bionic eye technology.

Working of Bionic Eye

- It works by capturing images with a small camera and transmitting the information to a processing unit that is attached to the eye.
- The processing unit then converts the visual information into electrical signals and sends them to an electrode array that is surgically implanted onto the retina.
- The electrodes stimulate the remaining healthy cells in the retina, which then sends signals to the brain to create the perception of vision.
- The restored vision is not perfect, but it can help people with vision loss to perform daily tasks more easily and safely.
- The amount and quality of vision that can be restored varies depending on the individual and the type of bionic eye being used.
- Some bionic eyes only restore basic visual shapes and patterns, while others can provide more detailed vision.
- The bionic eye is powered by a battery that is typically implanted behind the ear.
- The battery is recharged through a device that is held near the eye, which transmits power wirelessly to the battery.
- The device is typically rechargeable and can be used for several years before it needs to be replaced.

HEART AS A PUMP SYSTEM

Architecture

- The heart is a complex pump system that circulates blood throughout the body.
- It consists of four chambers: the right atrium, the left atrium, the right ventricle, and the left ventricle.
- Blood enters the right atrium from the body and is pumped into the right ventricle, which then pumps the blood to the lungs for oxygenation.
- Oxygenated blood returns to the heart and enters the left atrium, which pumps the blood into the left ventricle.
- The left ventricle then pumps the oxygenated blood out to the rest of the body. Between each chamber, there are one-way valves that ensure the blood flows in the correct direction and prevent backflow. The heart is also surrounded by the pericardium, a sac that contains a small amount of fluid and helps to protect and lubricate the heart as it beats

The Heart Beat

- The heart's pumping action is controlled by a complex network of electrical and chemical signals, which generate the rhythm of the heartbeat.

Electrical Signalling – ECG Monitoring and Heart Related Issues

- 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.

Heart attack: An ECG can help diagnose a heart attack by detecting changes in the heart's electrical activity that indicate a lack of blood flow to the heart.

Pace Makers

- A pacemaker is a small device that is surgically implanted in the chest to regulate the heartbeat.
- It is used to treat heart rhythm disorders, such as bradycardia (a slow heartbeat) or arrhythmias (abnormal heart rhythms), by delivering electrical impulses to the heart to regulate its rhythm.

The basic design of a pacemaker consists of:

Generator: The generator is the main component of the pacemaker and contains a battery and electronic circuitry to generate and control the electrical impulses.

Leads: Leads are thin wires that connect the generator to the heart and carry the electrical impulses from the generator to the heart.

Electrodes: The electrodes are located at the end of the leads and are used to deliver the electrical impulses to the heart.

Materials used in the construction of pacemakers include:

1. **Medical-grade plastics**: Medical-grade plastics, such as polycarbonate, are used to construct the exterior of the device and to provide insulation and protection for the internal components.
2. **Metals**: Metals, such as stainless steel and titanium, are used in the construction of the leads and electrodes to ensure their durability and long-lasting performance.
3. **Electronic components**: Electronic components, such as microprocessors, batteries, and capacitors, are used to control the delivery of the electrical impulses and to provide power to the device.

4. **Adhesives**: Adhesives, such as cyanoacrylate and epoxy, are used to secure the components of the device and to provide insulation and protection for the internal components.

Artificial Heart

An artificial heart is a device that is designed to replace the functions of a damaged or failing heart.

- It can be used as a temporary measure to support a patient while they are waiting for a heart transplant, or as a permanent solution for people who are not eligible for a heart transplant.

There are two main types of artificial hearts: **total artificial hearts** and **heart assist devices**.

- A total artificial heart is a self-contained device that completely replaces the functions of the natural heart. It is used as a bridge to transplant, meaning it provides temporary support to a patient while they are waiting for a heart transplant. **Heart assist devices**, are devices that are surgically implanted into the heart

  and work alongside the natural heart to support its functions.

While these devices are still in the early stages of development, they have the potential to greatly improve the survival and well-being of people with heart disease.

LUNGS AS PURIFICATION SYSTEM

The lung is divided into several parts

- **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 are larger airways that continue to branch into smaller airways called bronchioles.
- **Bronchioles**: The bronchioles are smaller airways that eventually lead to the alveoli. They are surrounded by tiny air sacs called 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.

Lungs as Purifier

The lung purifies air by removing harmful substances and adding oxygen to the bloodstream.

The process of purifying air in the lungs can be described as follows:

- **Filtration**: The **nose and mouth serve as a first line** of defense against harmful substances in the air, such as dust, dirt, and bacteria. The **tiny hairs in the nose, called cilia**, and the mucus produced by the respiratory system trap these substances and prevent them from entering the lungs.
- **Moisturization**: The air is also **humidified as it passes over the moist lining of the respiratory tract**, which helps to keep the airways moist and prevent them from drying out.
- **Gas Exchange**: Once the air reaches the alveoli, the gas exchange process occurs,

where **oxygen diffuses across the thin alveolar and capillary walls into the bloodstream**, and **carbon dioxide** diffuses in the opposite direction, from the **bloodstream into the alveoli** to be exhaled. This process ensures that the bloodstream is supplied with fresh, oxygen-rich air, while waste carbon dioxide is removed from the body.

- Overall, the lung serves as a vital purification system, filtering out harmful substances, adding oxygen to the bloodstream, and removing waste carbon dioxide. It plays a critical role in maintaining the body's homeostasis and supporting life.

Gas Exchange Mechanism of Lung

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.

SPIROMETRY

Spirometry is a diagnostic test that measures the function of the lungs by **measuring the 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.

Interpretation of Results

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.

Abnormal Lung Physiology – COPD

Abnormal lung physiology refers to any deviation from the normal functioning of the respiratory system.

This can be caused by a variety of factors, including diseases, injuries, or genetic conditions.

Some common examples of abnormal lung physiology include:

- **Asthma**: the **airways to narrow**, making it difficult to breathe.
- **Chronic obstructive pulmonary disease (COPD):** A progressive lung disease that makes it hard to breathe and can include conditions such as **emphysema and chronic bronchitis**.
- **Pulmonary fibrosis:** A disease in which **scar tissue builds up in the lungs**, making

it difficult to breathe and reducing lung function.

- **Pneumonia**: **inflammation and fluid buildup in the air sac**s.
- **Pulmonary embolism**: A **blockage in one of the pulmonary arteries**, usually by a blood clot, which can cause lung damage and reduce oxygen flow to the body.
- **Lung cancer:** A type of cancer that originates in the lung and can impair lung function by interfering with normal air flow and oxygen exchange.

Treatment for abnormal lung physiology depends on the underlying cause and may include medications, lifestyle changes, or surgery.

Artificial Lungs Artificial lungs are devices designed to mimic the function of the natural respiratory system.

They are used to support patients with acute respiratory distress syndrome (ARDS) or acute lung injury (ALI) and to help the patient's own lungs recover and heal.

Types There are two main types of artificial lungs: membrane oxygenators and extracorporeal lung assist devices.

Membrane Oxygenators: These are devices that use a semipermeable membrane to transfer oxygen and carbon dioxide between the blood and the air.

The blood is pumped through the membrane, where it comes into contact with air, allowing for the exchange of gases.

KIDNEY AS A FILTRATIONSYSTEM

- The kidney is a complex organ that acts as a filtration system for the body.]
- It **removes waste and excess fluid from the bloodstream** and maintains a delicate **balance of electrolytes, hormones, and other substances** that are critical for the body's normal functioning.
- The kidney also plays an important role in **regulating blood pressure** by secreting the **hormone renin**, which helps control the balance of fluid and electrolytes in the body.
- It also regulates red blood cell production and the levels of various minerals
- in the blood, such as calcium and phosphorus.
- Without the kidney, waste and excess fluid would accumulate in the body, leading to serious health problems

Architecture of Kidney: The kidney is composed of **functional units called nephrons**, Each kidney contains approximately one million nephrons, and each nephron performs the functions of filtration, reabsorption, and secretion.

The nephron is comprised of several key structures:

- **Bowman's capsule**: This is **a cup-shaped structure** that surrounds the glomerulus and filters waste and excess fluid from the bloodstream into the renal tubule.
- **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

Mechanism of Filtration – Urine

Steps involved in the filtration process:

- 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, is transported through the renal pelvis and ureters to the bladder, where it is eventually eliminated from the body.
- This process of filtration, reabsorption, and secretion helps to maintain the proper balance of fluids and electrolytes in the body, as well as to remove waste and excess substances.

Chronic Kidney Disease (CKD)

It is a long-term condition in which the kidneys gradually become less able to function properly.

Caused by a variety of factors, including diabetes, high blood pressure, and other health problems that damage the kidneys.

Symptoms - fatigue, swelling in the legs and feet, trouble sleeping, and difficulty concentrating.

As the disease progresses, it can lead to more serious complications, such as anemia, nerve damage, and an increased risk of heart disease and stroke.

Treatment - lifestyle changes - eating a healthy diet and exercising regularly, as well as medications to manage symptoms and underlying health conditions.

In severe cases, kidney transplant or dialysis may be necessary.

Regular check-ups and to talk to doctor

about how to best manage their condition

Dialysis Systems

Dialysis is a medical treatment that helps to filter waste and excess fluids from the blood when the kidneys are unable to function properly.

There are **two main types of dialysis systems**:

Hemodialysis is a procedure that uses a machine to clean the blood.

- 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.
- Hemodialysis typically takes place in a hospital or dialysis center, 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 the 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 and allows for more flexibility in scheduling.

Both hemodialysis and peritoneal dialysis can effectively treat the symptoms of kidney failure, but each has its own advantages and disadvantages.

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

An artificial kidney is **a device that is being developed to mimic the functions of the human kidney.**

The goal of an artificial kidney is to provide a more effective and efficient means of treating patients with chronic kidney disease, who currently rely on dialysis or kidney transplantation.

There are currently **two main approaches to developing an artificial kidney:**

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.**

Echolocation

Echolocation, also known as biological sonar, is a remarkable navigation and hunting technique employed by various animals, including bats, dolphins, and certain birds. These animals emit sound waves that bounce off objects in their environment, returning echoes that provide information about the location, size, shape, and movement of those objects. This ability allows them to effectively "see" their surroundings through sound, especially in conditions where vision is limited, such as darkness or murky waters.

In nature's sonar system, echolocation occurs when an animal emits a sound wave that bounces off an object, returning an echo that provides information about the object's distance and size. Over a thousand species echolocate, including most bats, all-toothed whales, and small mammals.

Human echolocation is the ability of humans to detect objects in their environment by sensing echoes from those objects, and by actively creating sounds: for example, by tapping their canes, lightly stomping their feet, snapping their fingers, or making clicking noises with their mouths.

Many blind individuals passively use natural environmental echoes to sense details about their environment; however, others actively produce mouth clicks and can gauge information about their environment using the echoes from those clicks. Both passive and active echolocation help blind individuals sense their environments.

Mechanics:

Vision and hearing are similar in that each interprets detections of reflected waves of energy. Vision processes light waves that travel from their source, bounce off surfaces throughout the environment and enter the eyes. Similarly, the auditory system processes sound waves as they travel from their source, bounce off surfaces, and enter the ears. Both neural systems can extract a great deal of information about the environment by interpreting the complex patterns of reflected energy that their sense organs receive. In the case of sound, these waves of reflected energy are referred to as echoes.

ULTRASONOGRAPHY:

Ultrasound refers to sound above the human audible limit of 20 kHz. Ultrasound of frequencies up to 10 MHz and beyond is used in medical diagnosis, therapy, and surgery. In investigative applications, an ultrasound source (transmitter) directs pulses into the body.

When the pulse encounters a boundary between organs or between two tissue regions of different densities, reflections of sound occur. By scanning the body with Ultrasound and detecting echoes generated by various organs, a sonogram of the internal structure(s) can be generated. The method is called diagnostic imaging by echolocation. Diagnostic ultrasound, also called sonography or diagnostic medical sonography, is an imaging method that uses sound waves to produce images of structures within your body. The images can provide valuable information for diagnosing and directing treatment for a variety of diseases and conditions.

SONARS:

Sonar (sound navigation and ranging or sonic navigation and ranging) is a technique that uses sound propagation (usually underwater, as in submarine navigation) to navigate, measure distances (ranging), communicate with or detect objects on or under the surface of the water, such as other vessels.

"Sonar" can refer to one of two types of technology:
Passive sonar means listening for the sound made by vessels;

Active sonar means emitting pulses of sounds and listening for echoes. Sonar may be used as a means of acoustic location and of measurement of the echo characteristics of "targets" in the water. Acoustic location in the air was used before the introduction of radar. Sonar may also be used for robot navigation, and SODAR (an upward-looking in-air sonar) is used for atmospheric investigations. The term sonar is also used for the equipment used to generate and receive the sound. The acoustic frequencies used in sonar systems vary from very low (infrasonic) to extremely high (ultrasonic). The study of underwater sound is known as underwater acoustics or hydroacoustic.

PHOTOSYNTHESIS:

Most life on Earth depends on photosynthesis. The process is carried out by plants, algae, and some types of bacteria, which capture energy from sunlight to produce oxygen (O_2) and chemical energy stored in glucose (a sugar). Herbivores then obtain this energy by eating plants, and carnivores obtain it by eating herbivores.

The Process:

During photosynthesis, plants take in carbon dioxide (CO2) and water (H2O) from the air and soil. Within the plant cell, the water is oxidized, meaning it loses electrons, while the carbon dioxide is reduced, meaning it gains electrons. This transforms the water into oxygen and the carbon dioxide into glucose. The plant then releases the oxygen back into the air, and stores energy within the glucose molecules.

Chlorophyll:

Inside the plant cell are small organelles called chloroplasts, which store the energy of sunlight. Within the thylakoid membranes of the chloroplast is a light-absorbing pigment called chlorophyll, which is responsible for giving the plant its green color. During photosynthesis, chlorophyll absorbs energy from blue- and red-light waves and reflects green-light waves, making the plant appear green.

PHOTOVOLTAIC CELLS:

WHAT IS PHOTOVOLTAIC?

The sun's copious energy is captured by two engineering systems: photosynthetic plant cells and photovoltaic cells (PV). Photosynthesis converts solar energy into chemical energy, delivering different types of products such as building blocks, biofuels, and biomass; photovoltaics turn it into electricity which can be stored and used to perform work.

Understanding better the way by which natural photosynthetic complexes perform these processes may lead to insight into the design of artificial photosynthetic systems and the development of new technologies for solar energy conversion.

A broad variety of bio-inspired concepts and applications are emerging, ranging from light-induced water splitting, Plant Microbial Fuel Cells to hybrid systems. These latter combine photosynthesis and photovoltaics and have great potential in Agri photovoltaic concepts such as the side-by-side arrangement of solar cells and plants, and systems consisting of transparent solar cells which are placed in front or above the plant. One of the applications that can contribute to bringing together the worlds of photosynthesis and photovoltaics is the photovoltaic cell.

solar cell

A solar cell, or photovoltaic cell, is an electronic device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon. It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Individual solar cell devices are often the electrical building blocks of photovoltaic modules, known colloquially as solar panels. The common single-junction silicon solar cell can produce a maximum open-circuit voltage of approximately 0.5 volts to 0.6 volts.

Application:

- Remote Locations
- Stand-Alone Power.
- Power in Space.
- Building-Related Needs.
- Military Uses.
- Transportation.

BIRD FLYING:

Bird flight is the primary mode of locomotion used by most bird species in which birds take off and fly. Flight assists birds with feeding, breeding, avoiding predators, and migrating.

Bird flight is one of the most complex forms of locomotion in the animal kingdom. Each facet of this type of motion, including hovering, taking off, and landing, involves many complex movements. As different bird species adapted over millions of years through evolution for specific environments, prey, predators, and other needs, they developed specializations in their wings and acquired different forms of flight.

GPS:

GPS is a system. It's made up of three parts: satellites, ground stations, and receivers. Satellites act like stars in constellations—we know where they are supposed to be at any given time. The ground stations use radar to make sure they are actually where we think they are. A receiver, as you might find in your phone or your car, is constantly listening for a signal from these satellites. The receiver figures out how far away they are from some of them.

Once the receiver calculates its distance from four or more satellites, it knows exactly where you are. Presto! From miles up in space your location on the ground can be determined with incredible precision! They can usually determine where you are within a few yards of your actual location. More high-tech receivers, though, can figure out where you are within a few inches!

GPS AND BIRD FLIGHT:

Scientists have long known that birds navigate using the earth's magnetic field. Now, a new study has found subtle mechanics in the brain of pigeons that allow them to find their way.

A team at Baylor College of Medicine in the U.S. identified a group of 53 cells in a pigeon's brain that record detailed information on the Earth's magnetic field, a kind of internal global positioning system (GPS).

Experiment:

Prof. Dickman and his colleague Le-Qing Wu set up an experiment in which pigeons were held in a dark room and used a 3D coil system to cancel out the planet's natural geomagnetic field and generate a tunable, artificial magnetic field inside the room. While they adjusted the elevation angles and magnitude of their artificial magnetic field, they simultaneously recorded the activity of the 53 neurons in the pigeons' brains which had already been identified as candidates for such sensors.

So, they measured the electrical signals from each one as the field was changed and found that every neuron had its characteristic response to the magnetic field, each giving a sort of 3-D compass reading along the familiar north-south directions as well as pointing directly upward or downward. In life, this could help the bird determine not only it's heading just as a compass does, but would also reveal its approximate position, the researchers said.

Each cell also showed a sensitivity to field strength, with the maximum sensitivity corresponding to the strength of the Earth's natural field, they added. And like a compass, the neurons had opposite responses to different field "polarity", the magnetic north and south of a field, which surprised the researchers most of all. Several hypotheses hold that birds' magnetic navigation arises in cells that contain tiny chunks of metal in their noses or beaks, or possibly in an inner ear organ.

However, the most widely held among them was thrown into question when researchers found that purported compass cells in pigeon beaks were a type of white blood cell.

AIRCRAFT: MECHANISM:

Lift, Drag, and Thrust:

The fundamentals of bird flight are similar to those of aircraft, in which the aerodynamic forces sustain flight lift, drag, and thrust. Lift force is produced by the action of airflow on the wing, which is an airfoil. The airfoil is shaped such that the air provides a net upward force on the wing, while the movement of air is directed downward. The additional net lift may come from airflow around the bird's body in some species, especially during intermittent flight while the wings are folded or semi-folded (cf. lifting body).

Aerodynamic drag is the force opposite to the direction of motion, and hence the source of energy loss in flight. The drag force can be separated into two portions, lift-induced drag, which is the inherent cost of the wing producing lift (this energy ends up primarily in the wingtip vortices), and parasitic drag, including skin friction drag from the friction of air and body surfaces and form drag from the bird's frontal area. The streamlining of the bird's body and wings reduces these forces. Unlike aircraft, which have engines to produce thrust, birds flap their wings with a given flapping amplitude and frequency to generate thrust.

<u>LOTUS LEAF EFFECT:</u>

The lotus leaf is well-known for having a highly water-repellent, or superhydrophobic, surface, thus giving the name to the lotus effect. Water repellence has received much attention in the development of self-cleaning materials, and it has been studied in both natural and artificial systems.

SUPERHYDROPHOBIC AND SELF-CLEANING SURFACES:

The self-cleaning function of superhydrophobic surfaces is conventionally attributed to the removal of contaminating particles by impacting or rolling water droplets, which implies the action of external forces such as gravity. Here, we demonstrate a unique self-cleaning mechanism whereby the contaminated superhydrophobic surface is exposed to condensing water vapor, and the contaminants are autonomously removed by the self-propelled jumping motion of the resulting liquid condensate, which partially covers or fully encloses the contaminating particles. The jumping motion of the superhydrophobic surface is powered by the surface energy released upon the coalescence of the condensed water phase around the contaminants. The jumping-condensate mechanism is shown to spontaneously clean superhydrophobic cicada wings, where the contaminating particles cannot be removed by gravity, wing vibration, or wind flow. Our findings offer insights into the development of self-cleaning materials.

Mechanism:

An autonomous mechanism to achieve self-cleaning on superhydrophobic surfaces, where the contaminants are removed by self-propelled jumping condensate powered by surface energy. When exposed to condensing water vapor, the contaminating particles are either fully enclosed or partially covered with the resulting liquid condensate. Building upon our previous publications showing self-propelled jumping upon drop coalescence (5, 6), we show particle removal by the merged condensate drop with a size comparable to or larger than that of the contaminating particle(s). Further, we report a distinct jumping mechanism upon particle aggregation, without a condensate drop of comparable size to that of the particles, where a group of particles exposed to water condensate clusters together by capillarity and self-propels away from the superhydrophobic surface.

Bioinspired Applications

Researchers and engineers have mimicked the lotus leaf's properties to develop materials with similar self-cleaning and water-repellent features:

- **Construction Materials**: Coatings inspired by the lotus leaf are applied to buildings, bridges, and pavements to prevent moisture penetration, thereby reducing corrosion and structural damage.
- **Biomedical Surfaces**: Superhydrophobic materials have been developed for stem cell cultures, minimizing contamination and improving cell growth environments.
- **Textiles**: Fabrics treated with lotus-inspired coatings resist water and stains, enhancing durability and cleanliness.
- **Optical Devices**: Anti-glare and self-cleaning surfaces for optical instruments have been created using lotus leaf-inspired designs, improving performance in various conditions.

<u>PLANT BURRS:</u>

A bur (also spelled burr) is a seed or dry fruit or infructescence that has hooks or teeth. The main function of the bur is to spread the seeds of the bur plant, often through epizoochory. The hooks of the bur are used to catch on to for example fur or fabric, so that the bur, which contains seeds, then can be transported along with the thing it attached itself to. Another use for the spines and hooks is physical protection against herbivores. Their ability to stick to animals and fabrics has shaped their reputation as bothersome.

Some other forms of diaspores, such as the stems of certain species of cactus also are covered with thorns and may function as burs. Bur-bearing plants such as Xanthium species are often single-stemmed when growing in dense groups, but branch and spread when growing singly.

The number of burs per fruit along with the size and shape can vary largely between different bur plants.

Relevance to humans:

Burs are best known as sources of irritation, injury to livestock, damage to clothing, punctures to tires, and clogging equipment such as agricultural harvesting machinery. Furthermore, because of their ability to compete with crops over moisture and nutrition, bur plants can be labeled as weeds and therefore also be subject to removal. Methods of controlling the spread of bur plants include the use of herbicides, slashing, and cultivation among others. Some have however been used for such purposes as fabric fulling, for which the fuller's teasel is a traditional resource. The bur of burdock was the inspiration for the hook and loop fastener, also known as Velcro.

VELCRO:

Mr. de Mestral examined the burr under a microscope and realized the small hooks of the burr and loops of the fur/fabric allowed the burr to adhere exceedingly well. This sparked his idea to mimic the structure as a potential fastener. Originally VELCRO is envisioned as a fastener for clothing, today, Velcro is used across a wide array of industries and applications; including healthcare, the military, land vehicles, aircraft, and even spacecraft.

SHARK SKIN:

The texture is rough since it has small scales similar to teeth, called Dermal Denticles. Each species has a uniquely shaped denticle. They have a covering of dentine, a central pulp canal containing blood vessels, and a single nerve. The denticles play an important part in swimming efficiency. The water is channelled by the ‘skin teeth' and flows across the fins and around the body. The teeth also break up the interface between skin and water, reducing the friction between the two entities. The teeth and skin also help protect the shark from injuries and several elements in the water. It's like a suit of armor for sharks.

Relevance to humans:

It is typically made with acetate and rayon yarns, as well as with worsted wool and various synthetic blends. The combination of the color of the yarns and the twill weaving pattern in which the colored threads run diagonally to the white yarns results in the finish for which sharkskin fabric is known. It has a smooth but crisp texture and a two-tone lustrous appearance. Lightweight and wrinkle-free, sharkskin is ideal for curtains, tablecloths, and napkins. Sharkskin fabric is popular for both men’s and women’s worsted suits, light winter jackets, and coats. Sharkskin is commonly used as a liner in diving suits and wetsuits.

SHARK SKIN AND SWIMSUITS:

Scientists have been able to replicate the dermal denticles in swimsuits and also the bottom of ships or boats. When cargo ships can squeeze out even a single percent in efficiency, they burn less bunker oil and don’t require cleaning chemicals for their hulls. Besides that, this sharkskin mechanism is also applied to create surfaces in hospitals that resist bacteria growth since the bacteria can’t catch hold of the rough surface.

KINGFISHER BEAK:

The kingfishers have long, dagger-like bills. The bill is usually longer and more compressed in species that hunt fish, and shorter and broader in species.

Relationship with humans:

Kingfishers are generally shy birds, but despite this, they feature heavily in human culture, generally due to the large head supporting its powerful mouth, their bright plumage, or some species' interesting behavior.

THE BEAK THAT INSPIRED A BULLET TRAIN:

The secret is in the shape of the kingfisher’s beak. A long and narrow cone, the kingfisher’s beak parts and enters the water without creating a compression wave below the surface or a noisy splash above. The fine point of the conical beak presents little surface area or resistance to the water upon entry, and the evenly and gradually enlarging cross-section of the beak keeps fluid flowing smoothly around it as it penetrates further into the water column. This buys the bird crucial milliseconds to reach the fish before the fish knows to flee. The length of the beak is critical here: the longer it is, the more gradually the angle of the wedge expands. A shorter, fatter, or rounder beak would increase the wedge angle, resulting in a splash, a compression wave, and a fleeing fish.

The Potential: Eiji Nakatsu, the chief engineer of the company operating Japan’s fastest trains, wondered if the kingfisher’s beak might serve as a model for how to redesign trains not to create such a thunderous noise when leaving tunnels and breaking through the barrier of tunnel air and outside-air. Sure enough, as his team tested different shapes for the front of the new train, the train became quieter and more efficient as the geometry of its nose became more like the shape of a kingfisher’s beak, requiring 15% less energy while traveling even faster than before.

HUMAN BLOOD SUBSTITUTES:

Human blood substitutes, also known as **artificial blood** or **oxygen therapeutics**, are engineered solutions designed to replicate certain functions of natural blood, primarily oxygen transport. They aim to address challenges such as blood shortages, the need for universal compatibility, and the risk of disease transmission associated with traditional blood transfusions

Shortages in blood supplies and concerns about the safety of donated blood have fueled the development of so-called blood substitutes. The two major types of blood substitutes are volume expanders, which include solutions such as saline that are used to replace lost plasma volume, and oxygen therapeutics, which are agents designed to replace oxygen normally carried by the hemoglobin in red blood cells. Of these two types of blood substitutes, the development of oxygen therapeutics has been the most challenging. One of the first groups of agents developed and tested were perfluorocarbons, which effectively transport and deliver oxygen to tissues but cause complex side effects, including flulike reactions, and are not metabolized by the body.

Other oxygen therapeutics include agents called hemoglobin-based oxygen carriers (HBOCs), which are made by genetically or chemically engineering hemoglobin isolated from the red blood cells of humans or bovines. HBOCs do not require refrigeration, are compatible with all blood types, and efficiently distribute oxygen to tissues. A primary concern associated with these agents is their potential to cause severe immune reactions.

Hemoglobin-based oxygen carriers (HBOCs) AND Perfluorocarbons (PFC) :

Hemoglobin-Based Oxygen Carriers (HBOCs) are engineered solutions designed to replicate the oxygen-transporting function of red blood cells. By utilizing modified hemoglobin molecules, these carriers aim to deliver oxygen to tissues, especially in situations where traditional blood transfusions are unavailable or contraindicated.

HBOCs are derived from purified hemoglobin—sourced from humans, animals, or produced synthetically—and chemically modified to function outside red blood cells. Modifications include polymerization, cross-linking, or encapsulation to enhance stability and reduce toxicity. These alterations prevent rapid breakdown and mitigate adverse effects like vasoconstriction.

Hemopure (HBOC-201): Derived from bovine hemoglobin, Hemopure is approved for human use in South Africa and has been utilized under compassionate use in the U.S. for patients refusing blood transfusions, such as Jehovah's Witnesses.

PolyHeme: A human hemoglobin-based product that underwent extensive clinical trials but was not approved due to safety concerns.

HemAssist: A diaspirin cross-linked hemoglobin that reached Phase III trials but was discontinued after studies indicated increased mortality rates.

ErythroMer: A next-generation, freeze-dried HBOC designed for easy storage and rapid rehydration. It mimics red blood cell oxygen delivery and has shown promise in preclinical studies.

Advantages of HBOCs

- **Universal Compatibility**: Lack of blood group antigens allows for use without cross-matching.
- **Extended Shelf Life**: Some HBOCs, like ErythroMer, are shelf-stable powders, eliminating the need for refrigeration.
- **Immediate Availability**: Useful in emergencies, remote locations, or military settings where blood supply is limited.
- **Reduced Infection Risk**: Being cell-free, HBOCs minimize the potential for disease transmission.

Challenges and Considerations

- **Safety Concerns**: Early HBOCs were associated with adverse effects, including vasoconstriction and increased mortality in some trials.
- **Incomplete Replication**: HBOCs primarily transport oxygen and do not perform other red blood cell functions like carbon dioxide removal or immune modulation.
- **Regulatory Hurdles**: Achieving approval requires extensive clinical testing to demonstrate safety and efficacy.

Perfluorocarbons (PFCs) are a type of artificial blood substitute that can dissolve and transport oxygen in the bloodstream. They are synthetic, fluorinated hydrocarbons that can dissolve significantly more oxygen than blood plasma. PFCs are being investigated as a potential alternative to blood transfusions, particularly in situations where immediate oxygen delivery is crucial.

Oxygen Delivery:

PFCs can dissolve and transport oxygen in the blood, which is essential for the body's cells to function properly. PFCs are chemically and biologically inert, meaning they don't react with the body's tissues or cells. PFCs are typically used in the form of emulsions, where they are suspended in a liquid medium to facilitate their circulation in the bloodstream.

Advantages over Hemoglobin-Based Substitutes:

PFCs offer several advantages over hemoglobin-based substitutes, including a lower risk of immunologic reactions, potential for mass production, and easier storage.

Clinical Applications:

PFCs have been explored for various clinical applications, including resuscitation, treatment of carbon monoxide poisoning, and improving tissue oxygenation in extreme cases.