TRENDS IN BIOENGINEERING (QUALITATIVE)

Muscular and Skeletal Systems as scaffolds (architecture, mechanisms, bioengineering solutions for muscular dystrophy and osteoporosis). Bioprinting techniques and materials, 3D printing of ear, bone and skin. 3D printed foods. Electrical tongue and electrical nose in food science, DNA origami and Biocomputing, Bioimaging and Artificial Intelligence for disease diagnosis. Self-healing Bioconcrete (based on bacillus spores, calcium lactate nutrients, and biomineralization processes) and Bioremediation and Biomining via microbial surface adsorption (removal of heavy metals like Lead, Cadmium, Mercury, and Arsenic).

MUSCULAR AND SKELETAL SYSTEMS AS SCAFFOLDS

Skeletal System as the Scaffold

Scaffolds are temporary structures used during construction. Similarly, the Bones in the human body act as a permanent scaffold Bones in the human body serve as a permanent scaffold. They are connected through joints, which allow movement and flexibility. Just as scaffolds are strategically designed to withstand forces during construction, the human skeleton is designed to withstand various pressures, stresses, and loads the body encounters during daily activities and movement.

Muscular System as the Scaffold

The **muscular system** can be likened to the **workers on the scaffold** who move and manipulate materials during construction. Muscles are attached to bones; when they contract, they pull on the bones, causing joint movement. This mechanism allows the body to perform various activities such as **walking, running, lifting, and grasping objects**. With exercise and training, muscles can strengthen and become more efficient.

Mechanism of the musculoskeletal system.

- Our nervous system **(brain and nerves)** sends a message to activate your **voluntary muscles**.
- **Voluntary muscle** takes up the muscle message and **activates itself.**
- **Tendons attach muscles to bones**. The tendon pulls the bone, making it move.
- To relax the muscle, your nervous system sends another message. It triggers the **message to relax the muscles**. The relaxed muscle releases tension, moving the bone to a resting position.

Muscular Dystrophy (MD)

- Muscular dystrophy is a group of diseases that cause progressive weakness and loss of muscle mass.
- MD is a progressive condition, which means it gets worse over time. It often begins by affecting a particular group of muscles, before affecting the muscles more widely.
- Some types of MD eventually affect the heart, or the muscles used for breathing, at that point the condition becomes life-threatening.

- There's no cure for MD, but treatment can help to manage many of the symptoms.
- MD is caused by changes (mutations) in the genes responsible for the structure and functioning of a person's muscles.
- The mutations cause changes in the muscle fibers that interfere with the muscles' ability to function. Over time, this causes increasing disability.

SCREENING & DIAGNOSIS

Blood tests

Damaged muscles release enzymes such as creatine kinase (CK) into the blood. High blood levels of CK suggest a muscle disease such as muscular dystrophy.

Electromyography

A thin-needle electrode is inserted through the skin into the muscle to be tested. Electrical activity is measured when relaxing and gently tightens the muscle. Changes in the pattern of electrical activity can confirm a muscle disease. The distribution of the disease can be determined by testing different muscles.

Ultrasonography

High-frequency sound waves are used to produce precise images of tissues and structures within the body. An ultrasound is a noninvasive way of detecting certain muscle abnormalities, even in the early stages of the disease.

Muscle biopsy

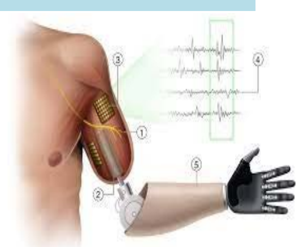
A small piece of muscle is taken for laboratory analysis. The analysis distinguishes muscular dystrophies from other muscle diseases. Special tests can identify dystrophin and other markers associated with specific forms of muscular dystrophy.

Osteoporosis

Osteoporosis is a medical condition characterized by decreased bone mass and density, leading to an increased risk of fractures. It occurs when the body's natural processes of bone resorption (breaking down bone tissue) outpace bone formation, resulting in brittle and weak bones. Osteoporosis is often called the "silent disease" because it typically progresses without noticeable symptoms until a fracture occurs.

BIO-ENGINEERING SOLUTIONS FOR OSTEOPOROSIS

1. Biomechanical Implants and Assistive Devices:



- Implants: Engineers are working on developing bioresorbable implants that can be placed in areas of weak bones to provide support during the healing process.
- Exoskeletons: Wearable exoskeletons can assist individuals with weakened muscles or bones maintain proper posture and mobility, reducing the risk of falls and fractures.

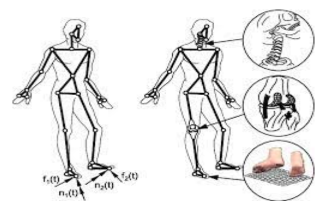
2. Bone Regeneration and Tissue Engineering:

- 3D-Printed Implants: 3D printing technology can be used to create custom implants that mimic the structure of bone tissue and encourage natural bone regeneration.
- Stem Cell Therapies: Stem cells can be manipulated to differentiate into bone-forming cells, promoting bone regeneration.

3. Diagnostic and Monitoring Tools:

- Advanced Imaging: High-resolution imaging techniques, such as micro-CT and MRI, can provide detailed information about bone structure and density, aiding in early diagnosis and monitoring.
- Wearable Sensors: Wearable devices can monitor gait, posture, and physical activity, providing insights into an individual's movement patterns and fall risk.

4. Biomechanical Research and Modeling:

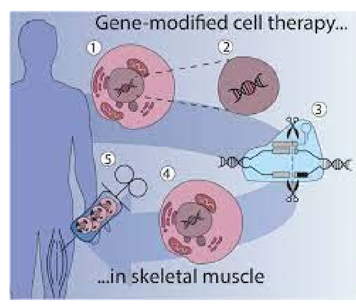


- Computational Modeling: Advanced computer simulations can model bone mechanics and predict fracture risk, aiding treatment planning and decision-making.

5. **Muscular dystrophy** (MD) refers to a group of genetic disorders characterized by progressive weakening and degeneration of the muscles. These conditions result from mutations in genes responsible for the structure and function of muscles. Muscular dystrophy can affect people of all ages and is typically inherited, meaning it is passed down from parents to their children.

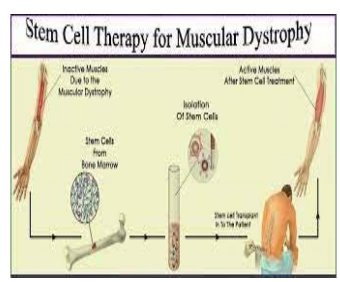
BIO-ENGINEERING SOLUTIONS FOR MUSCULAR DYSTROPHY

1. Gene Therapy:



- Gene Replacement: Gene therapy involves delivering functional copies of the defective gene responsible for muscular dystrophy into muscle cells. Viral vectors are often used to carry the corrected gene.
- CRISPR-Cas9: The CRISPR-Cas9 gene-editing system can correct mutations in the dystrophin gene, potentially restoring proper protein production.

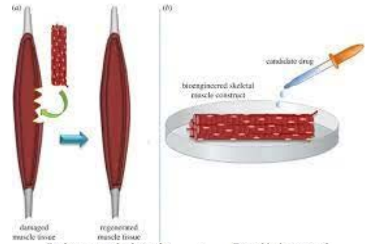
2. Cell Therapy and Regenerative Medicine:



- Stem Cell Transplantation: Stem cells, including mesenchymal stem cells and induced pluripotent stem cells (iPSCs), can regenerate damaged muscle tissue.
- Muscle Cell Engineering: Muscle cells can be engineered in the lab and transplanted into affected areas to promote muscle regeneration.

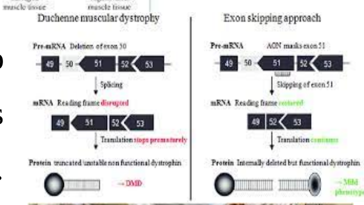
3. **Muscle Tissue Engineering:**

   3D Muscle Constructs: Engineers are working on creating 3D muscle tissue constructs in the lab using bioengineered scaffolds and muscle cells. These constructs could potentially be used for transplantation or drug testing.



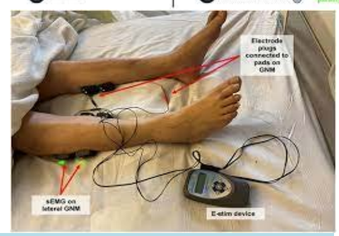
4. **Exon Skipping:**

   Exon skipping involves using synthetic molecules (oligonucleotides) to skip over specific exons in the dystrophin gene during protein production. This approach can lead to the production of a partially functional dystrophin protein.



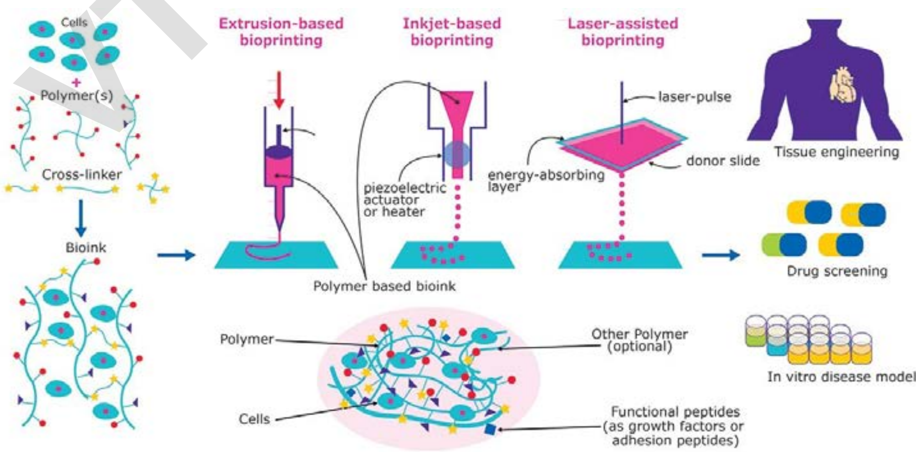
5. **Electrical Stimulation and Neuromuscular Interfaces:**

   Neuromuscular Prosthetics: Electrodes and neural interfaces can stimulate muscles and restore muscle function in individuals with muscular dystrophy.



BIOPRINTING TECHNIQUES AND MATERIALS

Bioprinting is an advanced manufacturing technology that involves the precise layer-by-layer deposition of biomaterials, such as cells and biocompatible scaffolds, to create complex three-dimensional (3D) biological structures. It has promising applications in tissue engineering, regenerative medicine, drug testing, and more.
Properties: Have appropriate viscosity, biocompatibility, and support cell function.



BASIC STEPS OF 3D BIOPRINTING (PROCESS)

The overall process of 3D bioprinting can be achieved via three distinct steps: pre-bioprinting, bioprinting, and post-bioprinting.

1. Pre-bioprinting

- The first step of pre-bioprinting is the formation of a model that is used by the printer and the choosing of materials to be used during the process.
- It begins with the extraction of biopsy of a tissue which provides a biological model that is to be recreated by the 3D bioprinting method.
- Technologies like computed tomography (CT) or magnetic resonance imaging (MRI) scans are used in this step.
- The images obtained through these methods are tomographically reconstructed to obtain 2D images.
- Cells necessary for the process are then selected and multiplied. The cell mass thus formed is mixed with oxygen and other nutrients to keep them viable.

2. Bioprinting

- The second step is the actual printing process where the bioink is placed in the printer to form a 3D structure.
- The mixture of cells, nutrients, and matrix, together forming bioink, is then placed onto the printer cartridge, which then deposits the material based on the digital model prepared.
- The formation of biological constructs involves the deposition of bioink onto the scaffold in a layer-by-layer approach to generate a 3D tissue structure.
- This step of the bioprinting process is a complex process as it requires the formation of different cell types based on the type of tissues and organs to be formed.

3. Post-bioprinting

- Post-bioprinting is the last step of the bioprinting process, which is important to provide stability to the printed structure.
- In order to maintain the structure and function of the biological matter, physical and chemical stimulations are required.
- These stimulations provide signals to the cells to reorganize and maintain the growth of tissues.
- In the absence of this step, the mechanical structure of the material might be disrupted, which then affects the functioning of the material.

3D PRINTING OF EAR, BONE, AND SKIN

3D printing of ear tissues is a promising application of bioprinting technology that aims to create customized ear structures for patients with congenital ear deformities, injuries, or other medical conditions.

3D Printing of Ear Tissues:

Process: Cartilage cells (chondrocytes) are combined with an appropriate bioink and printed into the desired ear shape.

The 3D Printing Process:

- **Imaging:** Start with detailed 3D scans or images of the patient's ear for customization.
- **Computer-Aided Design (CAD):** Use CAD software to design the 3D model of the ear tissue, considering anatomical accuracy.
- **Scaffold Printing:** 3D prints the scaffold using the chosen biocompatible material.
- **Maturation:** Culture the printed tissue in a bioreactor to promote cell growth and tissue development.
- **Implantation:** Once the tissue matures, it can be implanted into the patient. Surgical techniques may be required to connect nerves and blood vessels.

1. 3D Printed Ear:

- 3D printing allows for the creation of customized ear structures, including cartilage.
- Taking a small sample of the patient's ear to create billions of cartilage cells. The living cells are then mixed with collagen-based "bio ink," which is safe for the body.
- The 3D bio-printer uses that ink to create an object based on a digital model that copies the patient's healthy ear.
- Example: A 20-year-old woman who was born with the congenital disorder microtia and had one misshapen ear received the new appendage in March, 3D Biotherapeutics, the company that manufactured the ear. The ear was constructed from her own cells as a mirror replica of her other ear.
- Microtia patients are born without outer ears or with appendages that are smaller and different in shape. For these patient's 3D Bioprinting will be of great help.

2. 3D Printed Bone:

- 3D printing is used to create custom implants for bone defects or injuries.
- Even though other techniques like gas foaming, salt leaching, and freeze-drying have been employed to produce such hard tissues, 3D bioprinting produces the most accurate structures.

- The choice of materials, known as bioinks, is crucial. For bone printing, materials typically include a combination of biocompatible polymers (like PLA or PCL), ceramics (such as hydroxyapatite), and sometimes stem cells or growth factors to promote bone regeneration.

3. **3D Printed Skin:**

- Bioprinting is used to fabricate skin grafts for burn victims or patients with skin disorders.
- Bioinks may ***contain skin cells, collagen, and growth factors***.
- Production of functional tissues and organs at clinically relevant dimensions is challenging as the integration of the vascular network of arteries and veins and incorporation of various cell types to reinvent complex organ biology are not easy to achieve.

4. **3D printed foods**

- Typical 3D-printable foods are made of chocolate, cheese, and powdered ingredients like sugar or flour. Simulated meat, as well as cultured meat, are also possibilities.
- 3D printing in the food industry refers to the process of creating foods using 3D printing technology.
- The most commonly used technology makes use of food ingredients that are relatively viscous to ensure that, when extruded, the material keeps the intended form. The food is built up layer by layer until complete.
- 3D printers do not cook the food, but rather prepare them in the desired form. Thereafter, they may need to be cooked in an oven after the printing process is complete. Some foods, like sugar or chocolate, can be consumed directly after printing.

Bioprinting Materials:

Bioinks:

- **Composition:** Bioinks are the materials used for printing, typically consisting of living cells (e.g., stem cells, primary cells) and a hydrogel matrix (e.g., alginate, collagen, hyaluronic acid).

Scaffolds:

- **Composition:** Scaffolds are structural materials that provide mechanical support to the printed cells and guide tissue development. They can be made of biodegradable polymers like **polycaprolactone (PCL)** or natural materials like decellularized **extracellular matrix (ECM).**

Properties: Have appropriate viscosity, biocompatibility, and support cell function.

Applications:

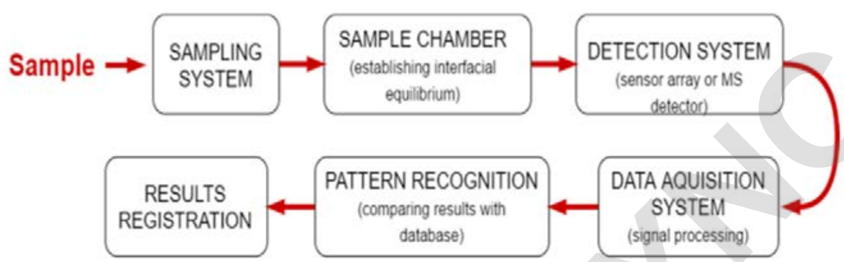
- **Skin Regeneration:** 3D bioprinting produces skin grafts for burn victims, enhancing healing and reducing scarring.
- **Bone and Cartilage Repair:** Custom bone and cartilage structures facilitate faster recovery and better integration.
- **Organ Regeneration:** Ongoing research aims to bioprint functional organs like kidneys, livers, and hearts.
- **Tumor Models:** Bioprinted tumor models mimic human cancers for accurate cancer biology studies and treatment testing.
- **Drug Testing:** These models allow for controlled testing of anticancer drugs, speeding up drug development.
- **Personalized Medicine:** 3D bioprinting creates patient-specific drug delivery systems, improving treatment outcomes.
- **Drug Screening:** Printed tissues and organs enable high-throughput drug screening with more relevant results.
- **Blood Vessel and Heart Tissue:** 3D bioprinting aids cardiovascular research and treatment development.
- **Heart Patches:** Printed heart patches repair damaged heart tissue for heart attack survivors.
- **Joint Replacement:** Customizable bioprinted joint replacements improve fit and function.

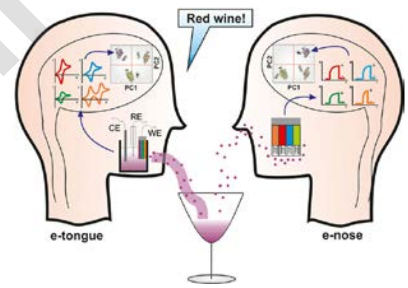
Limitations And Future Challenges:

- The primary barriers in bioprinting are suitable bioinks with high biocompatibility and mechanical strength.
- Bioprinter technology that is currently used has comparatively lower resolution and speed, which produces a challenge for future development. Similarly, the bioprinters should also be compatible with a wide spectrum of biomaterials.
- The speed of the bioprinting process should be increased to mass-produced biomaterials at a commercially acceptable level as the current speed is slow.
- There are some ethical issues with 3D bioprinting as the cost of the method might make it inaccessible to the poor.
- Because bioprinting is a novel technology, it should be studied sufficiently to ensure it is going to be safe for humans.

ELECTRICAL TONGUE AND ELECTRONIC NOSE IN FOOD SCIENCE

- The electronic tongue is an instrument that measures and compares tastes.
- As per the IUPAC technical report, *an* ***"electronic tongue"*** is an analytical instrument including an array of chemical sensors with partial specificity to different solution components, capable of recognizing quantitative and qualitative compositions of simple and complex solutions.
- Electronic noses and electronic tongue mimic the human smell and their communication with the human brain. Both often consists of non-selective sensors that interact with volatile molecules that result in a physical or chemical change that sends a signal to a computer which makes a classification based on a calibration and training process leading to pattern recognition.





An e-nose and e-tongue can be seen as an array of sensors able to generate an electronic signal in response to simple or complex volatile aroma compounds present in the gaseous sample. Electronic Nose consists of three major parts

1. **<u>Sample Delivery System:</u>** Generates volatile aroma compounds from the sample's headspace, which are then injected into the detection system.
2. **<u>Detection System:</u>** Comprising a sensor and a converter, volatile compounds adsorb onto the sensor surface, altering its physical properties and changing its electrical properties. This response is recorded and converted into a digital value.
3. **<u>Computing System:</u>** Records data and computers results based on a statistical model.

Applications:

- Conformity of raw materials, intermediate and final products
- Batch-to-batch consistency
- Detection of contamination, spoilage, adulteration
- Monitoring of storage conditions
- In process and production departments
- Managing raw material variability
- Comparison with a reference product

DNA ORIGAMI

- DNA origami involves the folding of DNA to create 2D and 3D objects at the nanoscale.
- Origami is a Japanese art of paper folding. The goal is to fold a flat sheet of paper into a finished sculpture. No cut, glue, or markings of the paper sheet should be used. Origami practitioners use a small number of basic folds to combine them into a variety of ways.
- DNA origami can be used to construct the most complex and refined two-dimensional DNA nanostructures, which subsequently serve as a template to assemble functional nanomaterials or molecules.
- The specificity of the interactions between complementary base pairs make DNA a useful construction material, through design of its base sequences.
- DNA origami refers to an assembly technique that folds single-stranded DNA template molecules into target structures. This is done by annealing templates with hundreds of short ‘staple’ DNA strands.
- The underlying principle for making DNA nanostructures are based on a simple rule: base-pair complementarity.
- Hydrogen bonds that pair the bases adenine and thymine, and cytosine and guanine allow complementary DNA strands to form into a double helix spontaneously.
- In general, the two DNA strands are fully complementary. However, if the two strands are only partially complementary, both strands can accept multiple DNA molecules. DNA can form a four-armed intermediary structure during cell division known as a Holliday junction.
- DNA origami has now emerged as a new way for the design and synthesis of defined two-and three-dimensional (2D and 3D) DNA nanostructures. The self-assembly reactions of DNA molecules enable the size expansion of the nanostructures.
- DNA origami is created via self-assembly. The combination of heat and chemical denaturation of double-stranded DNA scaffold strands in the presence of staple strands, followed by a sudden drop in temperature and stepwise dialysis to remove chemical denaturant favors self-assembly. For DNA origami production DNA complementary reactions are exploited for controlling DNA structures.

BIOCOMPUTING

- Biocomputing —a cutting-edge field of technology —operates at the intersection of biology, engineering, and computer science. It seeks to use cells or their sub-component molecules (such as DNA or RNA) to perform functions traditionally performed by an electronic computer.

- The procedure of DNA computing can be divided into three stages: encoding information, computation (molecular operations) and extraction of solution. The stage of encoding information is the first and most important step, which directly affects the formation of optimal solution.
- DNA computers will be used to solve complex problems.
- DNA computers will be able to solve problems in medicine, biology, engineering and cryptography, artificial intelligence, and data analysis.
- The goal of biocomputing is to mimic some of the biological 'hardware' of bodies like ours and to use it for our computing needs. From less to more complicated, this could include:
  1. Using DNA or RNA as a medium of information storage and data processing
  2. Connecting neurons to one another, like how they are connected in our brains
  3. Designing computational hardware from the genome level up Cells Already Compute

  Cells are far more powerful at computing than our best computers. For example:
  1. Cells store data in DNA
  2. Receive chemical inputs in RNA (data input)
  3. Perform complex logic operations using ribosomes
- 4. Produce outputs by synthesizing proteins
- Biocomputing's engineering challenge is to gain a granular level of control of the reactions between organic compounds like DNA or RNA.

BIOIMAGING

- Bioimaging refers to technologies for viewing biological substances that have been fixed for monitoring. In the fundamental and medical sciences, bioimaging can be used to examine typical anatomy and physiology and gather research data.
- There are certain medical imaging techniques including optical imaging (OI), magnetic resonance imaging(MRI), positron emission computed tomography, computed tomography (CT), radiography and conventional applied clinically.
- Bioimaging is a non-invasive process of visualizing biological activity in a specific period. It does not inhibit the various life processes such as movement, respiration, etc., and it helps to report the 3D structure of specimens apart from inferencing physically.
- Bioimaging gives clinicians a chief tool for checking patients' reactions to therapy. It promises illness detection in therapy in a non-invasive and safe manner. Bioimaging is a very important innovative imaging technology that has a lot of significance in today's world.

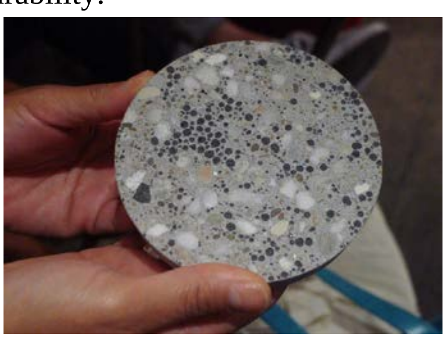
- The application of biomedical imaging for diagnosis and management of lifestyle-induced diseases will help to avoid disease development through lifestyle changes.

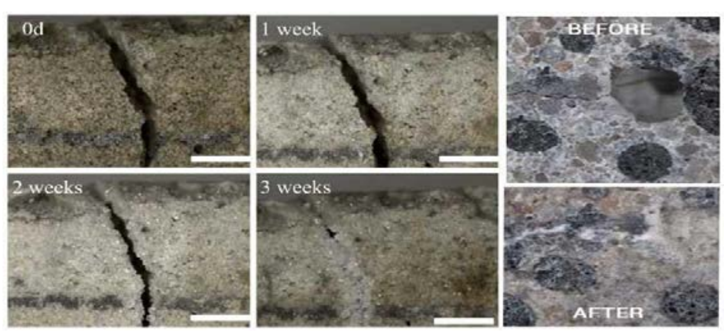
Artificial Intelligence for Disease Diagnosis

- In diagnosing the disease, the accuracy and correctness of the diagnosis is the most critical factor in the treatment process.
- AI has proven significant accuracy in the detection of image-based diseases as well as in the prediction of treatment outcomes regarding survival rate and treatment response.
- It can scan freeform text and pull data about specific symptoms, gene sequencing, or medical history. That information helps physicians screen patients for genetic conditions and diagnose rare diseases.
- AI techniques are used to predict diseases based on available patient data. Medical diagnosis requires physicians and medical laboratories for testing, while artificial intelligence-based predictive systems are used for the early prediction of diseases.

BIOCONCRETE

- Bio-concrete is a self-healing form of concrete designed to repair its own cracks.
- Bio concrete produces limestone ($CaCO3$) crystals to fill up the cracks appearing on the surfaces. When the cracks begin to form in the concrete structure water enters the cracks After encountering water and oxygen, the inactive bacteria become active.
- Self-healing concrete is a result of biological reaction of non-reacted limestone and a calcium-based nutrient with the help of bacteria to heal the cracks appeared on the building.
- Special type of bacteria's known as Bacillus are used along with calcium nutrient known as Calcium Lactate.
- Self-healing concrete (SHC) has the capacity to heal and lowers the requirement to locate and repair internal damage (e.g., cracks) without the need for external intervention.
- This limits reinforcement corrosion and concrete deterioration, as well as lowering costs and increasing durability.





Based On Bacillus Spores

- For the creation of healable cement concrete matrix, microbial self-healing solutions are significantly more creative and potentially successful.
- The addition of bacteria, mainly of the genus Bacillus, were studied for cracks- filling and increasing the compressive strength through $CaCO_3$-precipitation
- Gram-positive "*Bacillus subtilis*" (*B. subtilis*) microorganisms can effectively repair structural and non-structural cracks caused at the nano- and microscale.

B. subtilis bacteria greatly enhanced the compressive strength and speed up the healing process in cracked cement concrete mixture. The iron oxide nanoparticles were proven to be the best immobilizer for keeping B. subtilis germs alive until the formation of fractures.

Calcium Lactate Nutrients

- Calcium lactate comes in a liquid form and is added as a supplement in the water used for concrete mixing.
- The bacteria liquid culture and calcium lactate are added directly to the concrete mix.
- Calcium lactate is used to enhance the compressive strength and the self- healing of cracks.

Bio Mineralization Process

Biomineralization is the process by which mineral crystals are deposited in the matrix of living organisms , often to harden or stiffen existing tissues.

This process gives rise to inorganic-based skeletal structures such as bone during development, which is a complex and dynamic organ with both structural and metabolic functions.

BIOREMEDIATION

- Bioremediation is a biotechnical process, which cleans up contamination.
- It is a type of waste management technique which involves the use of organisms to remove or utilize the pollutants from a polluted area.
- There are several remedies where contaminated water or solid is purified by chemical treatment, incineration, and burial in a landfill. There are other types of waste management technique which include solid waste management, nuclear waste management, etc. Bioremediation is different as it uses no toxic chemicals.

- Microorganisms like Bacteria and Fungi are the main role player when it comes to executing the process of Bioremediation.
- Bacteria are the most crucial microbes in this process as they break down the waste into nutrients and organic matter.
- Even though this is an efficient process of waste management, but bioremediation cannot destroy 100% contaminants.
- Bacteria can easily digest contaminants like chlorinated pesticides or clean oil spills, but microorganisms fail to destroy heavy metals like lead and cadmium.

Types of Bioremediation,It is of three types:

1) Biostimulation

As the name suggests, the bacteria is stimulated to initiate the process. The contaminated soil is first mixed with special nutrients substances including other vital components either in the form of liquid or gas. It stimulates the growth of microbes thus resulting in efficient and quick removal of contaminants by microbes and other bacteria.

2) Bioaugmentation

At times, there are certain sites where microorganisms are required to extract the contaminants. For example – municipal wastewater. In these special cases, the process of bioaugmentation is used. There's only one major drawback in this process. It almost becomes impossible to control the growth of microorganisms in the process of removing the contaminant.

3) Intrinsic Bioremediation

The process of intrinsic bioremediation is most effective in the soil and water because of these two biomes which always have a high probability of being full of contaminants and toxins.

The process of intrinsic bioremediation is mostly used in underground places like underground petroleum tanks. In such place, it is difficult to detect a leakage and contaminants and toxins can find their way to enter through these leaks and contaminate the petrol. Thus, only microorganisms can remove the toxins and clean the tanks.

BIOMINING

Bioleaching (or biomining) is a process in mining and biohydrometallurgy (natural processes of interactions between microbes and minerals) that extracts valuable metals from a low-grade ore with the help of microorganisms such as bacteria or archaea.

Direct v. Indirect Bioleaching

Direct bioleaching uses minerals that are easily receptive to oxidation to create a direct enzymatic strike using the microorganisms to separate the metal and the ore.

In indirect bioleaching, microorganisms are not in direct contact with minerals during the process. However, leaching agents are created by microbes, which still oxidize the ore.

Biomining techniques may also be used to clean up sites that have been polluted with metals.

Valuable metals are commonly bound up in solid minerals. Some microbes can oxidize those metals, allowing them to dissolve in water. This is the basic process behind most biomining, which is used for metals that can be more easily recovered when dissolved than from the solid rocks.

Microbial Activities: Certain microorganisms, known as acidophiles, thrive in acidic environments and contribute to biomining by:Oxidizing metal sulfide ores to release metal ions,Promoting the dissolution of metals from ores and Concentrating metals in solution for subsequent recovery

Advantages of bioleaching include:

- Bioleaching can stabilise sulphate toxins from the mine without causing harm to the environment.
- Poisonous sulphur dioxide emissions harm the environment and can cause health problems for miners, and bioleaching avoids this process entirely.
- Bioleaching is more cost-effective than smelting processes.
- Some Bioleaching offers a different way to extract valuable metals from low-grade ores that have already been processed.
- Bacteria, archaea and fungi are typical prime bioremediates. The application of bioremediation as a biotechnological process involving microorganisms for solving and removing dangers of many pollutants through biodegradation from the environment.

Removal Of Heavy Metals

Bioremediation is an innovative technique for the removal and recovery of heavy metal ions from polluted areas and involves using living organisms to reduce and/or recover heavy metal pollutants into less hazardous forms, using the activities of algae, bacteria, fungi, or plants.

Heavy metals like Lead, Cadmium, Mercury, Arsenic can be removed by bioremediation and biomining process.