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Development Of Heart And Pancreas Using Medical 3d Printing Technology

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Abstract: With the use of computer-aided design (CAD) software, 3D printing is also known as additive manufacturing. There are various 3D printing technologies available, including Selective Laser Sintering (SLS), Stereolithography (SL), and Fused Deposition Model (FDM). Many biomedical materials, including metals, polymers, bioink, ceramics, and bioactive glasses, are used in it. Recent technological advancements in 3D printing have revolutionised the use of organ models, such as the intricate heart structure that is vital to human health maintenance. Hearts are frequently printed in three dimensions using FDM and polyjet technologies. Using 3D bioprinting, we are now in the early stages of creating artificial organs such as pancreas composed of pancreatic islets. The uses of 3D printing are outlined in this review. Because of its sustainable properties, which include low cost, minimal post-processing, and minimal material waste even when making complicated organs like hearts 3D printing is a technology of the future.

***Index Terms* – 3D printing, Computer-aided design, Selective Laser Sintering, Stereolithography, Fused Deposition Modeling.**

I. INTRODUCTION

Additive manufacturing or 3D printing, involves laying down successive layers of material under computer control to create three-dimensional objects of any shape starting with a 3D model or other electronic data sources and CAD (Computer Aided Design). Owing to the great degree of structural and compositional complexity seen in living tissues, it would be ideal to have a production technique that can accurately deposit various materials and cells in predetermined 3D spatial locations with the advancement of additive manufacturing (AM) techniques, or "3D printing," this capability was made possible [1]. the phrase "process of combining materials to manufacture products from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing procedures" (AM) refers to methods that create physical objects from three-dimensional (3D) digital data. Initially created in the 1980s, 3D printing technology also known as quick prototype technology has found widespread use across numerous industries, utilising diverse printing methods and materials [2]. These days, 3D printing technology presents a significant possibility for pharmaceutical and medical corporations to develop more specialised medications, facilitating the quick manufacture of medical implants and altering the way physicians and surgeons organise surgeries. There are many uses for this technology, but the development of 3D printing has been the fastest-growing innovation in the medical industry [3].

The advancement of 3D printing technology in recent years has led to a revolution in the applications of organ models. An increasing number of multidisciplinary researchers, physicians, and engineers with a range of backgrounds are working together to develop various organ models that are customised for each patient. In order to minimise time and danger during surgery, doctors utilise models to train skills, simulate procedures, and improve communication with patients prior to, during, and after surgery. Beyond surgery, models could be utilised in labs to enhance medical students' comprehension of concepts, in repeating experiments, or in testing medical equipment. Additionally, organ models support the growth of additive manufacturing in medicine, including biological 3D printing and artificial organs, by facilitating communication and collaboration between engineering and medicine. The issue of 3D printing organ models is expected to remain popular in the near future due to its significant potential to advance human health and life [4]. Successful experiments of 3D printed skin and tissues have already been conducted. Kidney, Pancreas, Liver, Heart, Brain and Bones are the 3d printing organs. Three-dimensional Printing have some advantages shortens the waiting period for organ transplants, Adaptable to the physical needs of the patient, Reduced possibility of being rejected, promotes innovative medical research. There are some disadvantages also high production costs, limited ability of an organ to operate, Possibility of organ rejection, lengthy production period.

As far as 3D printed organs go, the heart is essentially the holygrail. In addition to the heart's critical role in maintaining human health, scientists and researchers face a special hurdle due to the intricacy of the heart's vascularization. A group of experts from Carnegie Mellon University produced one of the biggest advances to date. Using the FRESH (Freeform Reversible Embedding of Suspended Hydrogels), they produced scaffolds made of collagen through 3D printing. Using a combination of collagen and pluripotent stem cells extracted from the patient's adipose tissue, a bio-ink was created as part of this technique. The prosthetic heart was then printed inside a moulded support gel to give it mechanical support. The fact that there have been significant advancements in this field over the past several years should provide hope to anyone who has been waiting for the day when organ replacements may be printed using 3D technology. Researchers concur that they learn something new with each artificial organ they construct, but there is still a great deal of trial and error involved. The group extracted pancreatic islets from animals and incorporated them into a bio-ink to develop the artificial pancreas. In this instance, the bioprinter was outfitted with two syringes: one for extruding the bio-ink mixture and pancreatic cells, and another for creating the blood arteries required to sustain the organ. The adult pancreas is a heterogeneous gland that is divided into an endocrine chamber and an exocrine chamber in the human body. The secretory cells that make digesting enzymes and discharge them into the pancreatic ducts make up the exocrine portion of the pancreas. The hormone producing islets that control glucose homeostasis make up the endocrine portion. The pancreas has roughly 1.5 million islets. Advanced 3D bioprinting technologies hold great promise for the development of type 1 diabetes treatments and pancreatic replacements [5].

II. Role Of Three-Dimensional Printing in Medical Field

Today's 3D printing technology offers a great deal of potential for pharmaceutical and medical companies to develop more specialised medications, to produce medical implants more quickly, and to transform the way surgeons and doctors arrange surgeries. Annually, 3D printing provides an increasing number of uses in the medical industry that enhance and save lives in ways that were previously unthinkable. Cardiothoracic surgery, cardiology, gastroenterology, neurosurgery, oral and maxillofacial surgery, ophthalmology, otolaryngology, orthopaedic surgery, plastic surgery, podiatry, pulmonology, radiation oncology, transplant surgery, urology, and vascular surgery are just a few of the healthcare settings including 3D printing in use [3].

The following are the primary direct uses of 3D printing in the realm of medicine and clinical:

Personalize surgical instruments and prostheses: 3D printing can be utilised to create one-of-a-kind implants, surgical instruments, and guides. As a result, because additive manufacturing reduces costs, surgical instruments and prostheses can be customised.

Examination of osteoporotic conditions: 3D printing can be helpful in verifying the patient's outcomes after a pharmaceutical intervention. This makes it possible to estimate the patient's bone state more accurately and to make better surgical treatment decisions.

Enhance forensic procedures: Using cross-sectional imaging, a 3D model might be utilised in court to help juries understand a variety of anatomic anomalies that would be difficult for them to understand.

Bioprinting: implantable tissue modelling is made possible by 3D printing. A few instances include the 3D printing of artificial skin for patients who have burn damage.

Personalized 3D printing of drugs: In order to have the drug layer dissolve more quickly than regular pills, it is printed as a powder during the 3D printing process.

III. BIOMEDICAL MATERIAL USED IN 3D PRINTING

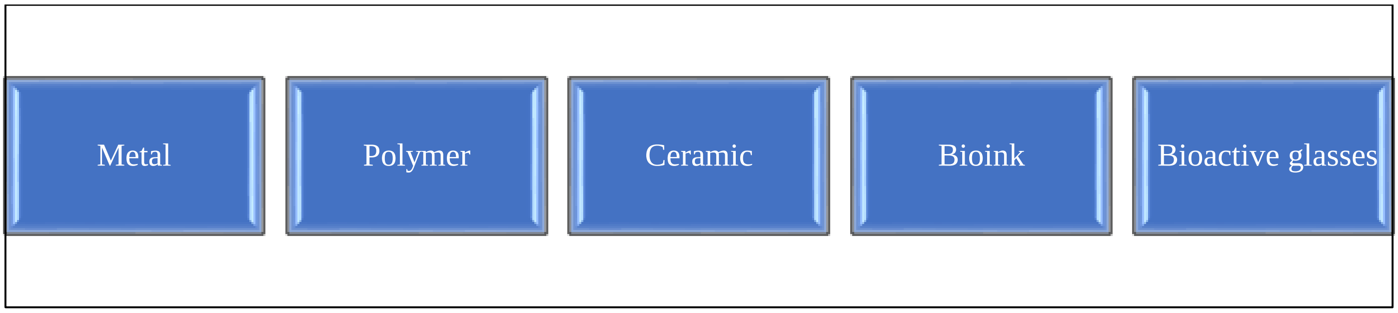

Fig.1 Biomedical Material.

a) Metal materials

Metals are mostly used in the preparation of permanent implants, such as dental or orthopaedic implants made of tantalum, cobalt-chromium, titanium, or stainless-steel alloys. Biomedical metal materials that are 3D printed provide benefits over conventional implants. Smaller grains and superior mechanical performance are common in 3D printed metal implants [6]. Furthermore, extremely regulated printing conditions provide a high degree of purity in the printed components, preserving the material's intended properties. Due to the cytotoxic Al or V in typical Ti6Al4V porous scaffolds, a variety of metal materials are being created for medicinal applications. Because of its low cytotoxic element content, high strength, excellent biocompatibility, and very low elastic modulus, Ti-Nb alloys, for instance, are more useful for biomedical applications [6].

b) Polymer materials

Medical models and biodegradable scaffolds are mostly made of polymer materials that include both natural and synthetic biomaterials. Collagen, fibrin, and chitosan are common natural medicinal polymeric materials. These polymers are very compatible, support cell adhesion and proliferation, and preserve cell morphologies, but their low mechanical strength is caused by their propensity to quickly deform [6]. It is possible to accurately adjust the shape, relative molecular mass, and degradation time of synthetic polymer materials, such as polycaprolactone (PCL), PLA, and PVA. It is simple to adapt the process for 3D printing antimicrobial polymers to other non-medical applications, like food packaging, water purification, or even the production of kid's toys.

c) Ceramic materials

Because of their constant physicochemical properties, high biocompatibility, and osteoconductivity, ceramic materials primarily HA and TCP are frequently utilised for prosthetic joints or dental implants. Their easily colorable 3D printed materials and adjustable sizes and shapes make them perfect dental materials as well. The majority of ceramics, in contrast to metals and polymers, exhibit distinct consolidation mechanisms and noticeable residual stresses upon sintering, which may have an impact on the mechanical strength and pore morphologies [6]. In vitro tests will be performed on cells to evaluate the toxicity of leftover binders. Enhancing totally dense ceramics' biomechanical qualities, printing resolution, biocompatibility, and sustained drug release should be the main goals of future research. Shape-memory materials (SMMs) are gaining significant interest as an alternative to standard materials.Reversible SMMs have the ability to change their structure or characteristics in a predetermined way in response to a certain external stimulus.

d) Bioink

The formulation of the bioink is crucial because the structure and composition of the material influence the phenotypic of the growing tissue.Bioink's mechanical and physical characteristics must be compatible with engineered tissue and guarantee printability. The rate at which bioink breaks down should be calibrated to match the cell's ability to restructure the extracellular matrix (ECM); nevertheless, the breakdown products must not be immunogenic or poisonous. Only a small portion of the biomaterials used in bioprinting are appropriate for skin bioprinting, despite their increasing number [7].

e) Bioactive glasses

Over the last ten years, scaffolds and implants made of bioactive glasses (BGs), glass-ceramics, and biopolymer-bioactive glass composites have been produced using a range of 3D printing techniques. A survey of the literature indicates that most investigations have focused on bioactive glass with a composition of 45S5 (45

SiO2, 24.5 CaO, 24.5 Na2O, and 6 P2O5) because of its ubiquitous availability. Since the various 3D printing processes range in the geometric precision and mechanical characteristics of the produced items, in-depth understanding of the specific.The capacities of every method ought to furnish details regarding their respective benefits and drawbacks when utilised in conjunction with bioactive glasses [8].

IV. Stages Of Bioprinting Process

The entire 3D bioprinting process can be finished in three separate steps: pre-bioprinting, bioprinting, and post-bioprinting.

a) Pre-bioprinting

This step also includes choosing the biomaterial or biomaterials and directly isolating the cells to obtain them at the necessary densities.tissue biopsy or traditional sub-culturing techniques in order to generate bioinks. It is mixed with oxygen and other nutrients to keep the cells alive [9]. The features of the constructs created during bioprinting are greatly influenced by the pre-bioprinting stage. To ensure that the necessary cell quality is obtained during the pre-bioprinting stage, which can then support tissue creation after bioprinting, it is imperative to adhere to the correct protocols.

b) Bioprinting

This is the phase where the printing process actually takes place. After that, the bioink is put into the printer cartridge, which deposits the material in line with the preset digital model created during the pre-bioprinting phase [9]. In order to produce 3D tissue constructs that mimic actual tissues, cell-rich. The substrate is covered with layers upon layers of bioinks. This is a difficult step in the bioprinting process because, depending on the tissues and organs being generated, printing may need the use of multiple cell types.

c) Post-bioprinting

The last stage of the bioprinting process required to provide functionality for the printed object is called post-bioprinting. The tissue structure is developed in an incubator during this phase, or ideally in a bioreactor. Stimulations both chemical and physical are needed to keep the structure and function intact[9]. These Cells get signals from simulations, which cause them to reorganise themselves in order to maintain tissue growth. A multitude of stimuli can be employed to regulate the tissue maturation process during post-bioprinting procedures due to the significant impact that post-processing environments have on cell-cell interactions.

V. PROCESSES IN 3D PRINTING

3D printing is a technology of the future due to its sustainable features, which include very low costs, less post-processing, and less material waste even when producing complicated items.

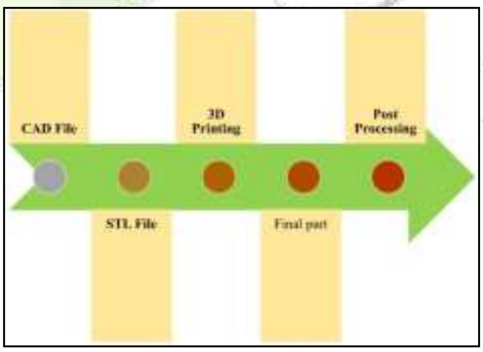

Fig.2 Basic process of 3D printers to create 3D object.

VI. Types of process in 3D printing

The two primary categories of AM techniques for biomaterials are cellular and acellular. Biomaterials are processed in an acellular manner without the presence of living cells, whereas cellular processing uses living biomaterials combined with cells[10]. According to the American Society for Testing of Materials (ASTM) Standard, acellular AM technologies can generally be divided into seven categories: 1) binder jetting, 2) directed energy deposition, 3) powder bed fusion, 4) material jetting, 5) material extrusion, 6) sheet lamination,7) vat photopolymerization, 8) Stereolithography (SL),9) Fused deposition modelling (FDM),10) Selective laser sintering (SLS)[11]

a) Stereolithography (SL)

Understanding the operation of the SL process is necessary before defining the word stereolithography. The system generates a CAD file, which is then translated to an STL file format to start the process. This STL file format offers the geometric information needed for a 3D printer to produce an object [11]. Ultraviolet (UV) curable photopolymer liquid, perforated table, laser source, and computer for process control are the four essential components that go into the formulation.3D printers begin operating in such a way that the perforated table is submerged in the liquid tank after they have read the STL file type.

b) Fused Deposition Model (FDM)

The FDM process forms 3D objects by pushing out layers of thermoplastic filament that has been dried to its melting point. Scott Crump presented FDM technology to Stratasys INC. in the United States in the early 1990s. Fused Deposition Modeling (3D) printers are equipped with a support base that has a degree of flexibility and is oriented to move vertically.Alongside the bottom plate is a companion extruder that joins the filament, heats it to the freezing point, and then uses a nozzle to extrude the filament layer by layer to create the desired object. With its supply, the extruder may move in all three directions (x, y and z). The term "fused deposition modelling" refers to the fact that the 3D printer is responsible for modelling the object since the neighbouring layers fuse together while the extruder completes the deposition process.

c) Selective laser sintering (SLS)

Using a fast-prototyping technique called Selective Laser Sintering (SLS), successive layers of powdered material are fused together to create intricate shape. CO2/nitrogen lasers, which count on the type of surface end and fusion required, aid in the solidification of layers. The purpose of this approach is to produce the object by using the chemical component powder[11]. The powder could be made of metal, glass, ceramics, thermoplastic, etc. This process is known as direct metal laser sintering if the powder is made of metal (DMLS). Two chambers make up an SLS printer; electricity is transferred from the first chamber to the second, which is where the actual production is done. The temperature at which the powder is heated is lower than the melting point of the comparable material. Layers are formed by the leveller or roller at the top, which surfaces the powder. Following the completion of manufacturing, finishing processes are needed.

Table no.1 Materials, properties and applications in SL, FDM and SLS method:

Materials	Properties	Applications
Materials, properties and applications in Stereolithography		
DC 100	Lesser shrinkage with higher accuracy.	utilised in the casting process of jewellery patterns.
DC 500	like natural wax and is prone to burning out.	for the creation of finely detailed, thinner jewellery wire motifs that are difficult to replicate using rubber moulding techniques.
Materials, properties and applications in Fused deposition modelling		
Glass Fiber Reinforced plastic (GFRP), Carbon Fiber Reinforced Polymer (CFRP) [11]	Compatibility with toughness, ductility, yield strength, etc.	Constructional applications
Bioink	Simple to print, possessing the appropriate mechanical qualities, biodegradable, and easily installable functional groups on the surface; superior post-printing maturation ability; biological compatibility; and the ability to	Bioprinted organs and scaffolds.

	maintain the 3D printed structure after printing.	
Materials, properties and applications in Selective laser sintering [11]		
Ceramics	Superior mechanical strength, excellent thermal and chemical stability, excellent hardenability, and useful optical, thermal, electrical, and magnetic properties.	Aeronautics, biomedical, metallurgical application.
Metals	Because of its high thermal conductivity, it is employed in selective laser melting.	Varied applications in various industries

VII. 3D PRINTING FOR ORGANS

a) HEART

The mechanical power and energy foundation used by the human body to carry out different physiological functions is found in the special structure of the heart, which consists of large and small blood vessels that tightly blend together as one. To effectively handle the repeated rebuilding of blood biochemistry, the striated muscle fibrous tissue which experiences autonomic contraction at the same electrophysiological rhythm is a crucial component of left-right cardiac coordination [12]. The heart in mature animals is about the size of a fist, with a stylized four-chambered muscular structure, and it functions as the cross-centre between the pulmonary and systemic circulations. In order to effectively pump new, high-oxygen blood throughout the body, the left heart is then squeezed full of it. In order to achieve optimal ejection and filling, the heart's muscle fibre population particularly the myocardial tissue that travels longitudinally, laterally, and obliquely along the ventricular wall must be present for the effective clockwise and counterclockwise torsional motion during systole and diastole [12].

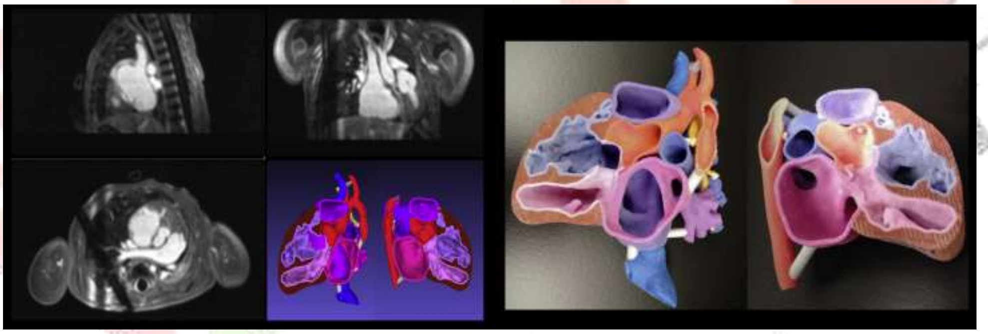

Fig.3 3D Printing of Heart

We begin our review by outlining the broad ideas and related procedures related to 3D printing, from phantom creation to cardiovascular imaging. To be more precise, we gathered comprehensive data and created important reader assistance covering image capture, segmentation, and registration possibilities, among other related activities. In order to provide a general overview of the subject and its lingering issues, we examine possible future advancements in 3D printing as well as related and competing technologies such as tissue engineering, virtual and mixed worlds, and vascular bioprinting [13].

3D phantoms can be printed using a variety of techniques after a virtual model has been developed. Since its introduction in the 1970s, 3D printing has been used to a variety of materials, such as polymers, metals, and alloys. It is now a well-established technology that is getting cheaper, more convenient, and more precise in terms of both resolution and complexity. The process of 3D printing for cardiovascular applications is difficult, and appropriate techniques should be chosen based on a variety of criteria, such as resolution, materials, and the physical attributes that the product needs to have, such as durability, colour and transparency, complexity, biocompatibility, cost, and recyclable nature [13].

Currently available 3D printing technologies:

Heart models have been printed using 3D printing methods such as polyjet and fused deposition modelling (FDM).

Fused deposition modelling (FDM)

The commonly used 3D printing method known as FDM usually uses thermoplastic filaments. To construct the 3D model, the filament is heated to the melting point and then extruded in layers from the printer nozzle [14]. The ability of FDM to produce incredibly accurate models and prototypes has shown its value in the field of cardiology. The FDM models were found to accurately represent the anatomy when compared to the dimensions from the medical images. Ninety-six percent of surgeons agreed that the models improved their understanding of CHD, and the 3D models altered the surgical decision in nearly half of the forty cases and improved the originally intended biventricular repair [14].

Polyjet

In that the 3D printed model is assembled layer by layer, Polyjet and FDM are comparable. But with polyjet printing, every layer of liquid polymer is cured and solidified by ultraviolet (UV) light; in contrast, with FDM printing, every layer of semi-molten material cools and hardens naturally [14]. With the capacity to build sophisticated, multicoloured, multimaterial models with smoother and thinner walls, Polyjet can create really accurate and smooth 3D models out of a vast array of materials for use as prototypes and parts. Polyjet 3D printing is the best method for producing patient-specific cardiovascular models due to the flexibility and intricacy of the final models. Although FDM and polyjet are widely used in cardiology for 3D printing, there exist other methods including digital light processing (DLP) and continuous liquid interface production (CLIP)[14]. DLP uses a projector to project the target object's cross-sectional picture onto a photosensitive

liquid resin.In that the resin used to print the model is cured using UV light, CLIP printing and polyjet printing are similar.The utilisation of DLP and CLIP, two cutting-edge technologies, may accelerate the production of 3D models and their future evolution, thereby propelling the area of cardiology and cardiovascular treatments forward.

Fig.4 Model of the heart and major arteries using a polyjet 3D printer.

b) PANCREAS

The most prevalent chronic illness in the world, diabetes has a significant negative impact on people's health. In light of this, research on diabetes, particularly islet functionalization, has gained popularity in academic institutions across the globe. A malfunction in the body's synthesis of insulin results in diabetes, which can take various forms. Blood glucose levels rise due to insulin resistance or insufficient insulin delivery in type 1 diabetes mellitus, a prevalent chronic condition caused by the immune system's persistent attack on and destruction of β cells. Insulin resistance is a key component of type 2 diabetes. Insulin can still be produced by the pancreas, but its effects on human organs are now diminished. Consequently, there is a noticeable deterioration in the overall function and quality of β cells as the synthesis of insulin increases continuously. Insulin injections and medication are now the methods used to manage type 1 diabetes in patients [5].

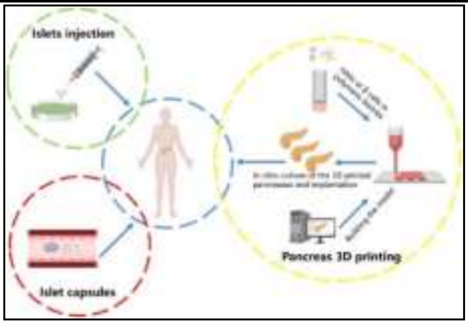

Fig.5 Diabetes treatment Strategies

Insulin injections or islet capsules are the standard treatments for Type 1 diabetes. The trend of 3D printing implantable pancreatic organs is growing in popularity as science and technology is advancing [5]. Printing cells, growth factors, hydrogels, and other biomaterials as "bioinks" to create bioartificial tissues and organs by automated layer-by-layer deposition procedures guided by computer-aided design (CAD) models is the hallmark of typical 3D bioprinting technology. In multi-nozzle 3D printers, distinct cell types can be encased in various polymeric "bioinks" and deposited concurrently. In order to create bioartificial tissues and organs with multicellular components, hierarchical structures (particularly branching vascular networks), and complex functions, 3D bioprinting a fully automated layer-by-layer additive manufacturing process can deposit cells, growth factors, and other biomaterials using rapid prototyping (RP) technologies. A wide range of living tissues and organs, including blood vessels, skins, bones, cartilage, hearts, and livers, have been successfully printed using 3D bioprinting methods.

We are currently in the early stages of developing an artificial pancreas made of pancreatic islets using 3D bioprinting. With this approach, pancreatic islets are usually encapsulated in bioinks that are dispensed into biopolymers that replicate the pancreatic microenvironment layer. layer, after which the bio-printed constructs are cultivated while occasionally supplemented with growth factors to start the bio-printed constructs' tissue functionality [9].

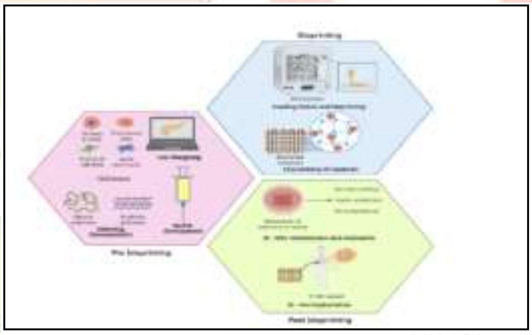

Fig.6 Schematic illustration of the application of 3D bioprinting technology for the development of bioartificial pancreas for patients with T1DM.

VIII. APPLICATIONS OF 3D PRINTING

a) Surgical Planning

A highly trained and experienced surgeon with the ability to make quick decisions is needed for operational surgery on a difficult congenital heart disease [15]. Making snap decisions during surgery will almost certainly result in extended operating periods, which could have a negative effect on the surgical result. For preoperative planning, Vodiskat et al. used a 3D printed model of the congenital cardiac defect.

b) Joint surgeries

The use of 3D-printed articular prostheses to rebuild joint function has produced good therapeutic results in joint surgery including the ankle, knee, hip, and shoulder [16]. Following total shoulder arthroplasty, a 3D printed shoulder glenoid prosthesis with its porous structure fills in severe bone defects in the joint well. A 2.5-year follow-up average shows good functional scores due to the component's additional threaded holes, which also enable conversion to a reverse construction.

c) Prostheses

In research by Suaste-Gómez et al., polyvinylidene fluoride was used to 3D print an ear prosthetic (PVDF). Through the use of an integrated astable multi-vibrator circuit, the prosthesis' sensitivity to temperature and pressure was investigated. Their innovative 3D-printed PVDF ear prosthetic demonstrated a significant degree of pressure sensitivity [15]. This is a positive outcome for applying the technique to additional biomedical engineering domains.

D) Bone tumor surgeries

In order to precisely restore each patient's distinct anatomy following bone tumour surgery, implants made through 3D printing might be the best choice. The conventional approach of treating osteosarcoma is amputation; however, this has a poor prognosis for long-term survivors and can result in limb impairment [16]. By restoring bone function and appearance, metal implants made by 3D printing greatly enhance the treatment of bone cancers.

e) Medical Education and Training

If one has access to high-quality CT scan data, 3D-printed models are typically anatomically accurate. But often, 3D-printed models are rigid, which complicates applicability in situations involving delicate tissue, like the brain. In order to produce realistic, physiologically appropriate, and deformable models of human brains, Ploch et al. proposed a very quick and affordable process that combined 3D printing, moulding, and casting. A substitute gelatin-like substance that closely resembles the mechanical characteristics of the human brain was employed.

f) Medical Research

The capacity to use 3D printing to mimic the behaviour of tumours has a significant impact on determining how well the various disease forms will respond to different therapies [15]. The advancement of microfluidics in bioprinting enables the creation of more complex tissue architectures akin to those found in genuine tissues and provides improved control over studies on 3D cell cultures. Drexel University researchers have developed 3D microfluidic devices embedded in PDMS that are packed with cells and offer better leak protection than previously known structures. They can now generate complicated tissue structures by guiding cells across a microfluidic network thanks to this breakthrough.

G) Organ Printing

Hydrogels were used as a cell scaffold by Cornell University researchers to demonstrate the 3D bioprinting of complete tri-leaflet heart valves. Onto the premade hydrogels, they print two distinct cell types: aortic smooth muscle cells and aortic valve leaflet interstitial cells. Throughout the course of seven days in culture, the cell-impregnated portions remained alive and maintained their tensile strength [15]. The printed cells displayed strong phenotypic retention, suggesting that they performed as expected, and good spreading, which produced a sturdy framework.

h) Drug Delivery

Using 3D bioprinting, researchers at University College London have created topical medicine delivery devices. They looked at the use of stereolithography (SLA) and fused deposition modelling (FDM) to create nose-wearing devices that administer salicylic acid to cure acne. Hot melt extrusion is used to load the salicylic acid into commercial polymer filaments [15]. This procedure benefits greatly from 3D printing since it allows for the creation of precisely fitting devices that maximise touch and provide a uniform dosage of medication based on scanned photos of the patient's anatomy.

IX. CONCLUSIONS AND FUTURE DIRECTIONS

In the future, scientists will find solutions to these issues so that tissue engineering and 3D printing can be successfully combined. Although cardiovascular 3D biofabrication and tissue engineering are still a ways off from clinical use, they have the potential to have a significant influence in the years to come by fusing modern manufacturing, cell biology, molecular biomarkers, and materials sciences. The area that will probably be affected the most immediately is probably the developing field of vessels-on-chip for cardiovascular medication toxicity testing in conjunction with cellular response monitoring. While the exciting prospect of printing entire organs and implanting them into patients is still a ways off, these methods are already proving useful in that they offer a unique window into biological mechanisms under controlled conditions, which creates a platform for limited and preliminary device testing. In the medium and long term, this will accelerate the transition to comprehensive patient-specific cardiovascular treatment, helping to achieve hitherto unachieved clinical result success rates.

Researchers from various domains, including medicine, biology, materials science, computer science, engineering, chemistry, and more, must collaborate to build a bioartificial pancreas organ that may be clinically implanted. Presently, practically all of the bottleneck issues for bioartificial pancreas engineering and production have been resolved using 3D bioprinting and cell encapsulation technologies. Future patient lives could be saved by 3D printing bioartificial pancreases, as stem cells, biomaterials, and 3D printers are developing at a rapid pace.

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