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A COMPREHENSIVE REVIEW ON 3D PRINTED ARTIFICIAL ORGANS

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Abstract:

Three-dimensional (3D) printing has emerged as a transformative approach in artificial organ fabrication, offering highly customizable, patient-oriented solutions. By employing advanced bioinks, stem cell scaffolds, and layer-by-layer bioprinting strategies, researchers are now able to create intricate tissue architectures that closely replicate native organ functions. This technology shows significant promise in addressing the persistent shortage of transplantable organs while reducing the likelihood of immune rejection. Key developments include the experimental creation of liver constructs, renal frameworks, and cardiac patches, yet the field still faces major hurdles such as achieving stable vascularization, ensuring long-term biocompatibility, and navigating complex regulatory pathways. Sustained interdisciplinary collaboration is critical for translating laboratory models into safe, clinically approved artificial organs for therapeutic use.

Keywords: 3D bioprinting, artificial organs, regenerative medicine, bioinks, tissue engineering, organ transplantation

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I. INTRODUCTION

Every year thousands of people lose their lives while waiting for an organ transplant.

Organ damage can be happened by Aging, Physical injuries and some internal conditions. To address this problem development of artificial organs is necessary. Recent advancements of technology, stereolithography also called as photo solidification which plays a major role in fabrication of organs.

Artificial organs are engineered medical devices, that are partial or whole replica of organs. Galletti proposed the following description of an artificial organ. "An artificial organ may be defined as a human made- devices designed to replace, duplicate or compound, functionally or cosmetically, a missed, diseased or else incompetent part of the body, either temporarily permanently which requires a non-biological material interface with living tissue". [6]

II.SIGNIFICANCE OF ARTIFICIAL ORGAN

Artificial organs are human made devices that engage with living cells. Construction of artificial organs and transplantation(replacement) of the organs with artificial one is time taken and overpriced process . Based on materials used artificial organs are classifies into 3 types :

1. Mechanical- made from synthetic, non living materials like polymers , plastics.
2. Biochemicals made of partially living cells
3. Biological comprises of living cells , biodegradable polymers. [17]

III.OVERVIEW OF 3D PRINTING

The concept of 3D printing began in the 1980s with Charles Hull's invention of stereolithography. Initially this technology is applied in industries such as aerospace. 3D printing merges computer-aided design (CAD), materials science, and engineering to construct three-dimensional structures, including biological organs.

One of the advantages of 3D printing for medical use is its ability to utilize a patient's own cells

(autologous cells), which reduces the risk of organ rejection. A fundamental concept of creating functional organs is the development of vascular networks, which provide blood and nutrients to the tissue.
3D bioprinters are equipped with nozzles and optical systems managed by specialized software, which deposits layers of materials onto a substrate, building the organ layer by layer.[(7)(5)(10)]

IV.Types of process

3D printing of artificial organs is also known as bioengineered organs differs from traditional one. As 3D printing uses various biocompatible materials that contains both living cells and biomaterials which are moulded to form a structure suing CAD technology. Hence, developing bioink formulations that meet both physicochemical and biological requirements for 3D bioprinting applications is one of the major challenge . The biomaterials used must be compatible with the cells to impart its viability, proliferation3D printed organs serves as both prosthetics and functional . This process typically begins with biomedical imaging like MRI,CT scanning from where the outline of structure is build by CAD .Micro and macro structures can be studied with this technology. The regulatory framework is not yet developed ,but attempts to keep up with technological evolution. Manufacturers must generate the preclinical data to estimate safety and efficacy.Following approval
through Investigational New Drug (IND) application s to the Food and Drug Administration (FDA) or its global counterparts is crucial before clinical trials begins under strict monitoring conditions. [(2)(3)(16)]
3Types of 3D printing ways are used in case of organ fabrication:

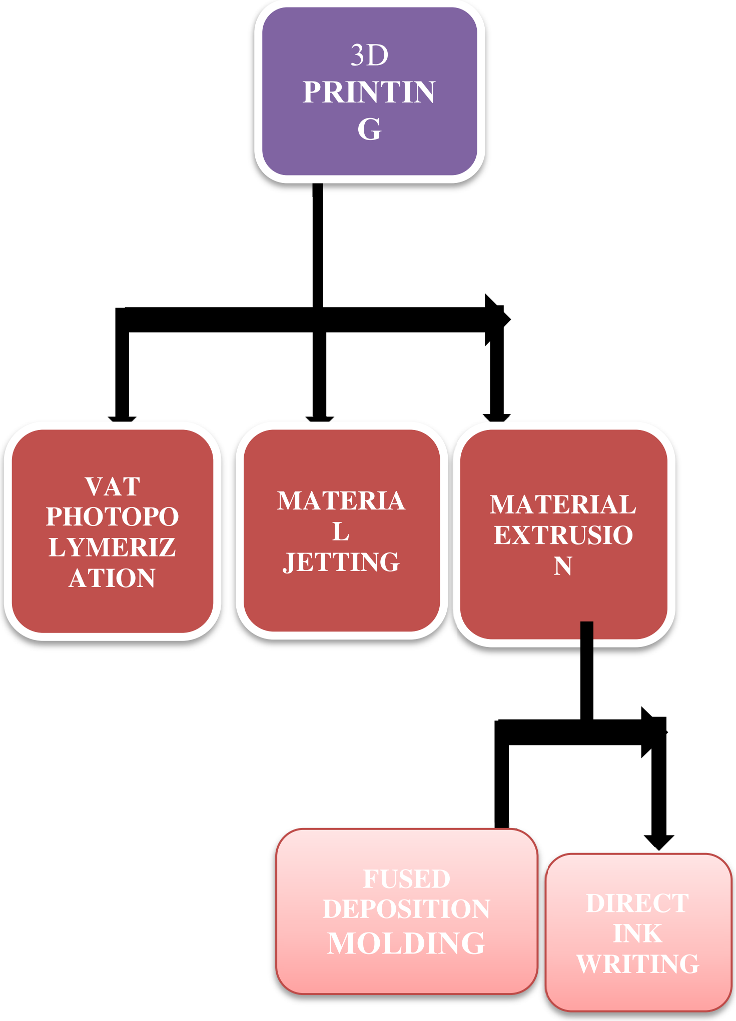
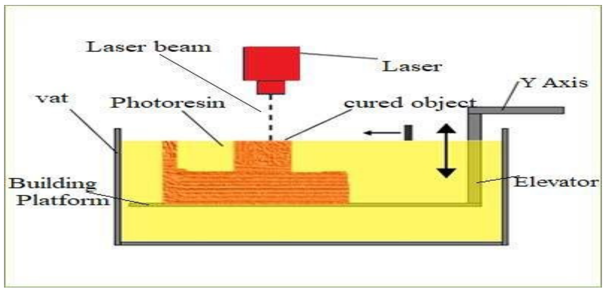


Fig. 1 Types of 3D Printing process



Vat Photo polymerization

Fig. 2 Islam, Rofiqul & Sadhukhan, Pinkan. (2021). an insight of 3d printing technology in pharmaceutical development and application : an updated review. 7. 55-80.

A. Vat photo polymerisation

This technique involves use of light sensitive polymers that are solidified precisely in required areas in the presence of specific light like UV. In the presence of UV light liquid polymer is converted to solid form. [(2)]

B.Material jetting

Also referred to as the inkjet printing method, this is a non-contact bioprinting process where small droplets of bioink are ejected from a nozzle and deposited onto a substrate in a controlled manner with the help of computed systems. The droplets can vary in size depending on the method used to deform the nozzle either thermally or via piezoelectric actuators. In thermal inkjet systems, heat from an actuator forms a vapor bubble that propels the ink droplet out of the nozzle. In piezoelectric inkjet bioprinting utilizes voltage-induced deformation of the ink chamber to control droplet release. The size, shape, and surface tension of the droplets can be precisely regulated by adjusting the voltage. Aided by CAD software, UV light is used to cure the droplets, creating a patterned structure layer by layer.[2][20]

C.Material extrusion

Similar to material jetting, material extrusion uses a nozzle-based system to deposit bioink. It often employs pneumatic pressure, though mechanical drives can provide more accurate spatial control. A drawback of pneumatic systems is the delayed response caused by gas compression. Both pneumatic and mechanical systems are capable of handling highly viscous materials, but mechanical systems often offer finer spatial resolution. The quality of extrusion-based printing depends on various factors such as nozzle diameter, pressure, material type, and deposition rate. Typical resolution ranges from 200 to 100 micrometers.[18]

a. Fused deposition moulding :

Also known as **Fused Filament Fabrication (FFF)**, FDM is an additive manufacturing process where thermoplastic materials like PLA, ABS, and PEI are melted and extruded through a heated nozzle. The molten filament is laid down layer by layer according to the design, gradually building up the organ structure. The thermoplastic filament is loaded into the printer and heated to a specific temperature. Once molten, the filament is extruded in thin strands that cool and solidify quickly, with the build platform moving along the X, Y, and Z axes to shape the object. Cooling fans are often used to accelerate solidification. After each layer is completed, the platform lowers, and the next layer begins.[18]

b. Direct ink writing :

In this method, viscoelastic materials are used as the printing ink. The ink is extruded through a nozzle to form layers, ultimately solidifying into the desired 3D shape. Also known as **Robocasting**, DIW enables high-precision fabrication of micro- and meso-scale structures.
The process consists of three main steps:

(1) creating a 3D model using CAD software,

(2) generating a movement path for the nozzle using slicing tools, and

(3) depositing the ink layer by layer. [2][9][20]

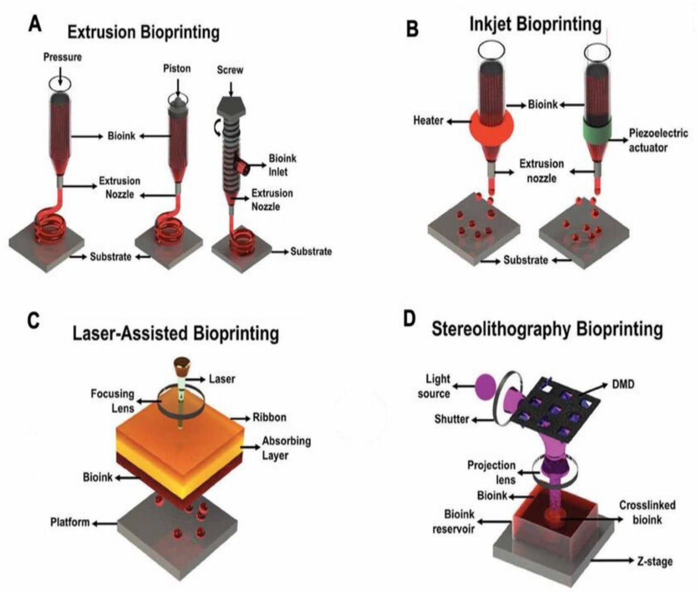


Fig. 3 Tavafoghi, Maryam & Darabi, M.A. & Mahmoodi, Mahboobeh & Tutar, Rumeysa & Xu, Chun & Mirjafari, Arshia & Billi, Fabrizio & Swieszkowski, Wojciech & Nasrollahi, Fatemeh & Ahadian, Samad & Hosseini, Vahid & Khademhosseini, Ali & Ashammakhi, Nureddin. (2021). Multimaterial bioprinting towards the fabrication of biomimetic tissues and organs. Biofabrication. 13. 10.1088/1758-5090/ac0b9a.

V.Examples

1.Ancient artificial organ (replacement therapy):

The replacement of missing or non-functional body parts with engineered devices has been practiced for thousands of year. One of the foremost examples includes prosthetic feet. In modern times, advancements in medical technology have improved the customization and functionality of such prosthetics.(6)

2.Reconstructive Surgery

3D printing plays a vital role in reconstructive surgery. An example is from 2013, when the U.S. Food and Drug Administration approved a customized cranial implant which was developed by Oxford Performance Materials. The implant was created using CT scan data, that helped to construct 75% of a patient's skull. (6)

3.Heart Valves:

Artificial heart valves are designed in various forms, such as caged-ball, tilting disc, and bileaflet valves. The caged and tilting types are more likely to cause damage to blood cells, bileaflet valves offer better flow dynamics and less backflow. (12)(13) These valves can be made from metals or biological materials, including porcine, bovine, or human tissues, forming what are known as bioprosthetic valves.(4)(11)(14)(15)

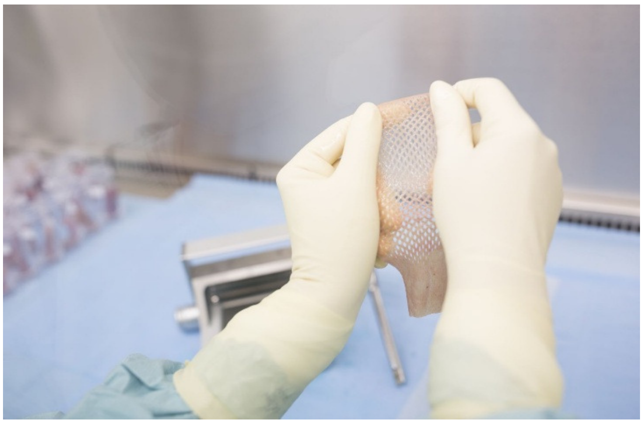
Bileaflet valve

Fig. 4 **Mechanical Heart Valve Replacements Devices**

4.Skin Substitutes

The skin is the body's outermost layer, composed of various cell types. Generally the body heals wounds naturally using fibrin and collagen . These biomaterials mimic the properties of natural skin by offering

protection from infection, maintaining elasticity, and preventing moisture loss. In an experimental study, Fu et al. explored the use of 3D-printed artificial skin incorporating human adipose-derived stem cells. (9)(19)(21)



Artificial skin

Fig. 5 Skin Grafts and Biologic Skin Substitutes: Overview, Relevant Anatomy, Graft Survival and Healing

5. Bone Regeneration:

Bone is a complex structure made of bioceramics and connective tissue that supports the body, protects organs, and produces blood cells. Its architecture spans multiple scales—from the macro-level (cortical and cancellous bone) to nano-level

features like mineralized collagen fibres. This hierarchical design is essential for mechanical stability, nutrient transport, and cellular interactions. Using 3D bedside bioprinting, researchers have developed bone scaffolds for procedures such as cranioplasty. One such scaffold, created from polycaprolactone, replicated the external structure of the skull. Inside, hydrogels containing bone marrow-derived mesenchymal stem cells (BMSCs) were used to emulate cancellous bone. Lab studies confirmed that these scaffolds promoted stem cell differentiation into bone-forming cells. In a subsequent animal study, beagle dogs received cranial implants using this method, which led to successful bone regeneration over a 9-month period.[(1)(2) (9)(21)]

Regulatory aspects:3 d printing is a additive manufacturing technology that enhances the scope in engineering , product design , and also in medicine.3DPritning is used to create actual structures based on information technlogy and using cad technology. Last year , a drug that treats seizures was designed n 3d printing and named it as Spritam.

China:

It created the "Additive Manufacturing Industry Development Action Plan(2017-2020)" in 2017 as an action plan for the growth of the 3DP industry. A year later, China's Center for Medical Device Evolution published rules for licencing and regulating 3DP medical devices, including those made to order via additive manufacturing

US:

US Government is still processing the use of 3DPrinting.[(8)]

VI.BENEFITS:

- ❖ A large number of patients die in search and wait of organ transplant . In that case artificial organ using 3D printing is in high demand.
- ❖ In traditional where organ transplantation had issues of graft rejection in 3D printed artificial organ fabrication patients own cells are used so there is no graft rejection.
- ❖ Working on natural organs costs a lot so by using 3Dprinted organs production is of low cost.
- ❖ It is a faster and precise approach.
- ❖ Animal testing has decreased with the use of 3 D printing. The number of animals killed annually to serve clinical studies and trials have also reduced.
- ❖ Moreover there is a less need to take high strength dose after surgery.

VII.CHALLENGES:

- ❖ In artificial organs as part of biopolymers as scaffolds are used which has to meet the requirement of biocompatibility with the living cells.
- ❖ Several challenges are there in tissue maturation steps in printing that are needed to be addressed.
- ❖ Selection of bioink also plays a crucial role in the organ printing as they act as a medium to protect the cells.
- ❖ On the other hand, to achieve the desired fabricated tissue equivalent important bioink properties such as rheological characteristics, cell–ECM interactions, gelation kinetics, material properties, and cell source should be considered . It is important that the bioink formulation be stable enough to ensure that the tissue construct remains structurally stable.
- ❖ Processing time and cost are the other major challenges that prevent mass production and should be analysed in each specific application.
- ❖ The scaffolds must have mechanical strength and vascularization to perform necessary function.

VIII.CONCLUSION:

Every year thousands of patients are in need for organ transplant and about 20 deaths are listed per day waiting for organ transplant.3D printing plays an important role in precision medicine.3D printing technology using various software and technologies along with the actual MRI and CT images to print organs which can overtake the functions of organs and there by increases the quality of life . As it uses patients tissues with scaffolds which implies that there is less and almost no chances graft rejections.

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