3D printing Modern Medical Applications: Review
3D printing has brought a revolution in Medical field

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Abstract: 3D Printing is an Additive Manufacturing process which has brought a new revolution in overall manufacturing processes by spreading its applications in all fields of science without having any barriers. In this paper we are going to study the present applications of 3D printing in different fields and we are going to discuss the possible future applications.

Index Terms **– 3D printing, Organ printing, Medical, Bio-printing.**

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1. INTRODUCTION

3D Printing sometimes referred as Additive Manufacturing process is a computer controlled sequential layering of materials to create 3D shapes or models. It is useful to manufacture complex shapes or components. It was first developed in the years 1980's by having few applications because of difficulty in printing and expensive in cost. After 2000's it became affordable and has become viable for a wide range of applications like Food, Cloth, Shelter, Safety, Health, Education, Mass production, Apparel, Automotive, Aerospace and so on.

2. 3D PRINTING TECHNIQUES

2.1 Drop-based type of bio-printing (Inkjet)

Drop-based bio-printing have been used to produce three-dimensional biological tissue. Printer cartridges are filled with a suspension of living cells and a smart gel. Alternating patterns of the smart gel and living cells are printed using a standard print nozzle, with cells eventually fusing together to form tissue. When completed, the gel is cooled and washed away, leaving behind only live cells. This type of technique is commonly used due to its efficient speed, though this aspect makes it less suitable for more complicated organ structures.

2.2 Extrusion type of bio-printing

Extrusion bio-printing involves the constant deposition rate of printing material from an extruder. This tends to be a more controlled process of cell deposition and allows for greater cell densities which can be used in the construction of 3D tissue or organ structures. But this technique entails slower printing speeds. This technique sometimes coupled with UV light, to form a more stable and integrated construct. [3]

3. PRINTING MATERIALS

3D bio-printing usually consist of alginate or fibrin polymers that have been integrated with cellular adhesion molecules, which support the physical attachment of cells. These polymers are specifically designed to maintain structural stability.

Printing materials must fit a broad spectrum of criteria that the resulting scaffolds should be physically and chemically appropriate for cell proliferation. Biodegradability is another important factor. The 3D printing, materials used must be customizable and adaptable for a wide array of cell types and structural conformations.[6]

Hydrogel alginates are the most commonly used materials in organ printing research, as they have highly customizable property, so that they can be fine-tuned to simulate certain mechanical and biological characteristics of natural tissue. The ability of hydrogels makes them to be used as an adaptable scaffold material.

4. MEDICINE

The application of 3D printing in medicine can provide many benefits, including: the customization and personalization of medical products, drugs, and equipment; cost-effectiveness; increased productivity; the democratization of design and manufacturing; and enhanced collaboration

5. APPLICATIONS

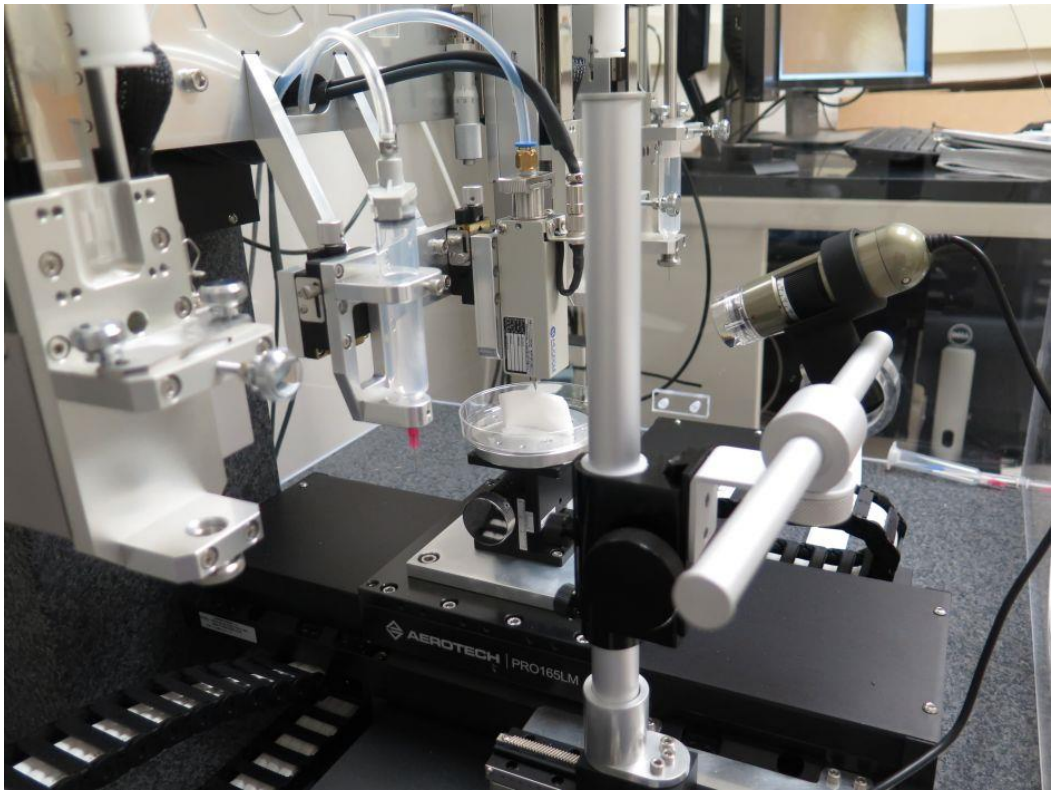
5.1 ORGAN PRINTING

Organ printing involves three sequential steps: pre-processing or development of 'blueprints' for organs; processing or actual organ printing; and post-processing or organ conditioning and accelerated organ maturation.

The primary purpose of organ printing is transplantation. Research is currently being conducted on artificial heart, kidney, and liver structures, as well as other major organs. For more complicated organs, such as the heart, smaller constructs such as heart valves have also been the subject of research. Some printed organs such as the bladder, as well as vascular structures such as urine tubes have already reached clinical implementation.

3D printing allows forming a cell scaffold, this will be followed by the process of cell seeding. Additionally, the process of integrating cells into the printable material itself is also done.

Researchers at Wake Forest University in North Carolina say they have created a 3D printer that can produce organs, tissues and bones that could theoretically be implanted into living humans.

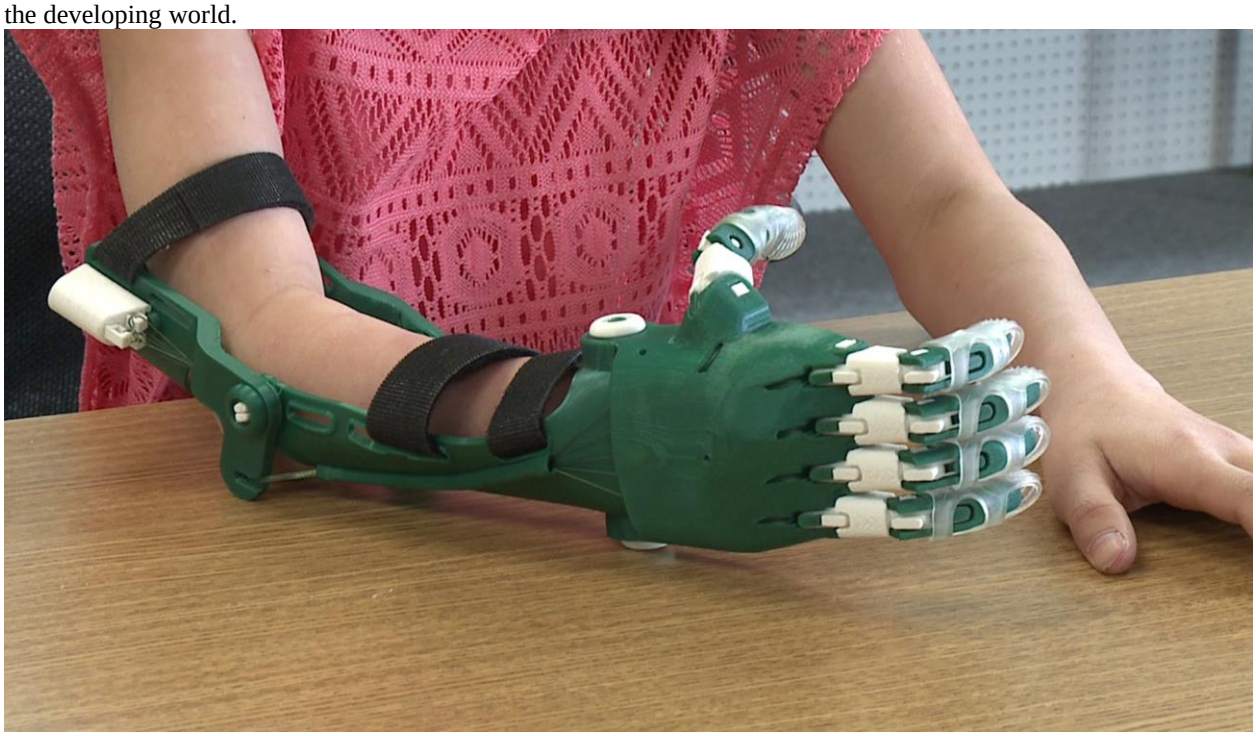


1. Wake Forest's 3D printer in action. (Wake Forest Institute for Regenerative Medicine)

5.2 PROSTHETIC PARTS

80 percent of the world's amputees do not have access to modern prosthetics. Creating traditional prosthetics is very time–consuming and destructive, which means that any modifications would destroy the original molds. 3D Printers can be used to quickly produce cheap and customizable prosthetic parts.[2]

Researchers at the University of Toronto used 3D printing to quickly produce cheap and easilycustomizable prosthetic sockets for patients in the developing world.



2. 3D printed prosthetic hand developed by California scientists

"Not Impossible Labs" company in California took 3D printers to Sudan where the war has left many people with amputated limbs. The organizer's trained locals how to operate the machinery, create patient specific limbs, and fit themselves.

5.3 BONES

Patients in need of skeletal augmentation, such as those with facial asymmetry resulting from trauma or congenital malformations, would have used a bone implant that best fits their anatomy. Typical bone augmentation implants are made from alloplastic materials (such as PEEK or titanium) or the patient's bone is cut and repositioned[2]

Susmita Bose, Professor of Washington State University modified a 3D printer which binds chemicals with a ceramic powder and creates intricate ceramic scaffolds that promote **the growth of the bone**. It helps in hip and knee replacements which lasts longer by developing a body-friendly calcium phosphate-based coating for the implant materials.

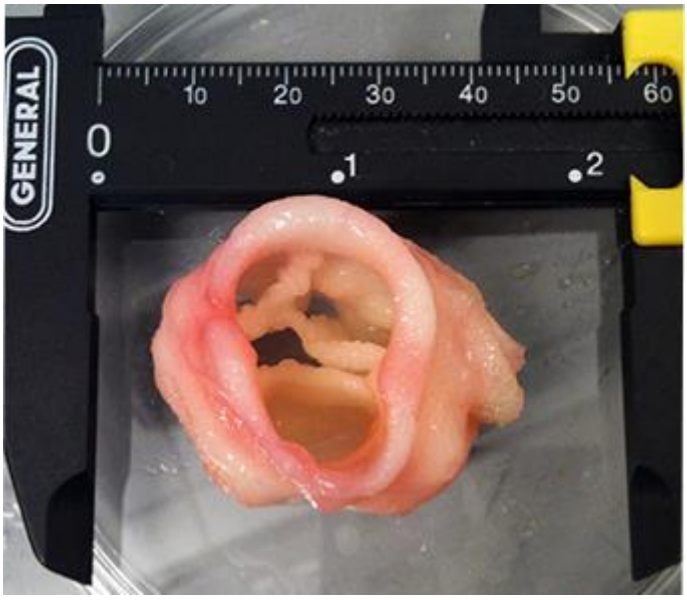
A new synthetic material called hyperelastic bone (HB) has been developed for reconstructive surgery. It can be implanted under the skin as a scaffold for the growth of a new bone or it can be used to replace the lost bone material. Although it has not been tested in humans, the first animal experiments appear to have been successful.

5.4 VALVES

Professor, Jonathan Butcher of Cornell University has **3D printed a heart valve** having similar functions as the original valve. It has tested in sheep. He used a combination of cells and biomaterials to control the valve's stiffness. Professor believes bio-printing will gain much more attention in the tissue engineering and biomedical field over the next decade.[4]

Aortic valve disease is a serious condition affecting people of all ages. Congenital heart valve defects are very dangerous for newborns and may be fatal if left untreated. The most recommended treatment is the replacement of the defective valve's surgery. Although prosthetic valve replacement is a standard process for adults, prosthetometric devices are not suitable for young adults and adults.

A popular technique in the world of advanced production, 3D printing, has been modified to create precise three-dimensional structures of living tissue.



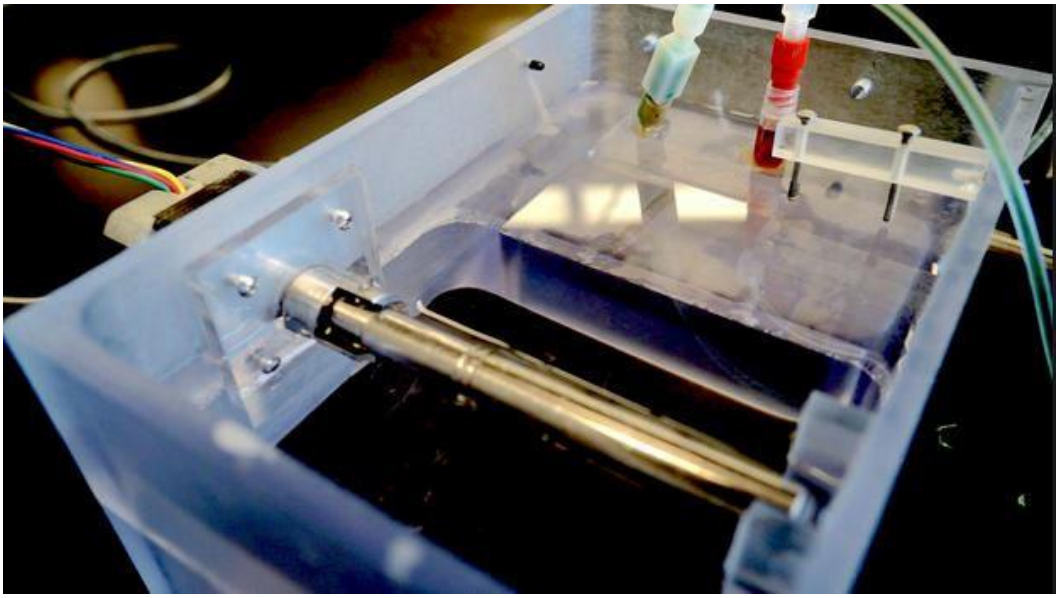
3. A 3D print of an artificial heart valve image : Jonathan T. Butcher, Cornell University

5.5 SKIN

3D bioprinting is an excellent platform for the precise deposition of biomaterials and living cells to make biomimetic skin, in large volumes with great repeatability. However, non-uniform skin pigmentation is often seen, and this remains a huge challenge to be solved.[1]

To create pigmented skin constructs, the researchers used three different types of skin cells: melanocytes, keratinocytes and fibroblasts, as well as a two-step bioprinting method called drop-on-demand.

Researchers at the Wake Forest School of Medicine in the US developed the prototype of a 3D printer which can able to create synthetic skin. It is used for transplanting to patients, who suffered from severe burn injuries.



4. An image showing 3D printing of skin, taken from cbsnews

Much of the action takes place in the printer's cartridge. The red solution, dyed that way for the demonstration, consists of skin cells, which are harvested from the patient, analyzed and multiplied in the lab.

The green solution will form the skin's 3D scaffolding, "to organize the red material and keep it in place," explained LianLeng, one of the lead developers of the printer

5.6 DRUGS

A drug or drug is a drug used to cure or ameliorate the symptoms of a disease or condition. The application can also be a preventive medicine that has benefits for the future but is not related to existing or pre-existing illness or symptoms.

Recently Food and Drug Administration developed an epilepsy drug called Spritam by using3D printers. The 3D printer prints out the powdered drug layer by layer to make it more dissolve faster than other pills. [2]

5. An image of 3D printed drug by a chemist at the University of Glasgow

5.7 CRANIUM REPLACEMENT

The skull present in head is a bony structure. It supports facial structures and provides protection for the brain. The skull consists of two parts: cranium and mandible. In humans, these two parts are the neurocranium and the viscerocranium, which contains mandible as its largest bone.[5]

Dr. Ulianovsky created a mold using 3D printer with the help of a CT scan of the patient's head which was taken with each 'slice' image produced at a distance of 1.25 mm from the last. This allowed him for assembly into a detailed three-dimensional model of the skull. The measurements for the missing piece were taken from the other half of the skull by taking assumption that the skull is symmetrical. He used Protakril-M, a cold-cure acrylic powder (often used in dental practice for the creation of dentures and orthodontic appliances) among other things.

6. BENEFITS OF 3D PRINTING IN MEDICAL APPLICATIONS

- Customization and Personalization

One of the greatest advantages is to produce custom-made medical products and equipment. For example customized prosthetics and implants can provide great value for both patients and physicians. Apart from this it can also produce jigs and fixtures for use in operating rooms which will have a positive impact on surgery time and patient recovery time.

- Increased Cost Efficiency

It has the ability to produce items cheaply and can also reduce manufacturing costs by decreasing the use of unnecessary resources. Some drugs may also be printed in dosage forms that are easier and more cost-effective to deliver to patients.

- Enhanced Productivity

It enhances the productivity by making much faster than traditional methods of making prosthetics and implants, which require milling, forging, and a long delivery time. Properties like resolution, accuracy, reliability, and repeatability are also improving.

7. CHALLENGES

1. Cell proliferation provided by bio-printing is conducted in an artificial environment, which are different from natural biological signaling processes which prevents the development of appropriate cellular morphology.

2. Another challenge is the need to vascularize artificial structures such as blood vessels for cellular sustainability, which allows the diffusion of key nutrients and oxygen.

3. Bio-printing material (bio ink) needs to be printable and economically feasible. It should have the capability of forming safe intended structures.

8. FUTURE SCOPE

There are no limits for the applications of 3D printer. Due to its reliability, it may be used to print valves or cells during operating a patient or printing skin during operating burned people. In depth research may results in production of bones which are stronger and better than present ones. By using sophisticated facilities and technologies organs printing can be done faster during transplantation. Among all other fields we can assure that the best future of 3D printer lies in Medical field.

9. CONCLUSION

By stating few examples of 3D printing applications in Medical field in this paper, we can say that it has become a “boon” for doctors as well as patients, by solving many complicated cases and leading a way for making new innovations. By considering above applications and innovations, It may not be a wonder for us if I state that there may be a chance of 3D printing of whole human body in coming few decades. The advancement of medicine achieved through 3D printing is already significant and exciting,[3] but some more revolutionary applications need to be evolved.

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