

Present Status and Prospects of 3D-printed Organs

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Abstract. This paper develops into the status and prospects of 3D printing technology in the medical field, particularly its application in organ construction. Amidst the escalating demand for organ transplants, traditional methods struggle to maintain a balance between supply and demand, posing notable limitations. 3D printing technology, with its unique additive manufacturing capabilities, presents a promising solution. By utilizing biomaterials and living cells, this technology can fabricate tissues and organs with biological activity and intricate structures, offering new avenues for addressing the organ shortage challenge. And it emphasized that 3D printing technology has made a great contribution to advancing medicine and enhancing human health. By printing customized, patient-specific organs, the risk of rejection is reduced, increasing the long-term success rate of organ transplantation. Research into 3D-printed organs has accelerated the scientific understanding of organ development and lesions and has played a positive role in the discovery of previously unimaginable therapeutic strategies and treatments. The paper also discusses the current progress and remaining challenges in 3D-printed organs, encompassing soft and hard tissue organs, as well as complex organs like the heart and brain. Ultimately, it highlights the potential of 3D printing to revolutionize organ replacement and medical treatment.

Keywords: 3D printing, Organ construction, Biological activity, Medical application.

1. Introduction

In the present generation, 3D printing as an emerging technology is slowly penetrating all kinds of industries, becoming a technology with revolutionary significance. Especially in the medical field, the application of 3D printing technology is particularly remarkable, which has gradually achieved the ability to build tissues and even organs with biological activity and tiny structures. At present, according to statistics, China's supply and demand for organ transplantation are very unbalanced, Lai and Yang pointed out that the grim status quo of China's organ donation, and the emergence of 3D printing technology provides a new way of thinking about the solution of this problem [1]. Jia elaborated on the application of 3D bioprinting technology in the medical field, highlighting its unique advantages in building biological structures [2].

In the application, there have been, for example, studies by Yang and Deng et al. in the application of printed artificial bone to the human body, where they have mentioned that the printed tissues are characterised by a high degree of matching and strength, but also by the obvious disadvantages of a long production time and high cost [3].

However, although much progress has been made in 3D-printed organ research, challenges are still being faced. How to ensure the long-term survival and functional recovery of printed organs, and how to achieve large-scale production are all key issues that need to be resolved at present. This article intends to combine and analyse the existing literature to provide an in-depth discussion on various aspects, such as the technical basis, research status, and current challenges and limitations. Specifically, this article will first introduce the basic principles and advantages of 3D printing technology, and then provide a detailed introduction to the status of printing soft tissue organs, hard tissue organs, and complex organs, respectively. On this basis, this paper will further analyse the challenges and limitations of the current research and put forward corresponding solutions and prospects, hoping to provide a reference for the development of this technology.

2. 3D Printing Technology Basics and Advantages

2.1. Definitions and Fundamentals

2.1.1 Definition

3D printing technology, also known as additive manufacturing or rapid prototyping, is a technology that constructs objects by printing materials layer by layer based on a digital model. It uses software for computer-aided design to transform the digital model into a physical model, and quickly achieves the manufacturing of objects by stacking materials layer by layer. It has the characteristics of high printing precision and a short production cycle.

2.1.2 Fundamental

As shown in Fig. 1, the basic principle of 3D printing technology can be divided into three steps: the first is modelling, through the computer-aided design software to accurately build a three-dimensional digital model, and then the designed model will be transformed into a file format such as STL or OBJ to ensure compatibility with the printing equipment; followed by slicing, the step is to use professional software to subdivide the model into a series of levels of thin layers, and to plan a corresponding Finally, printing begins. The printer will follow the designed process, adding material layer by layer until the completed product is printed.

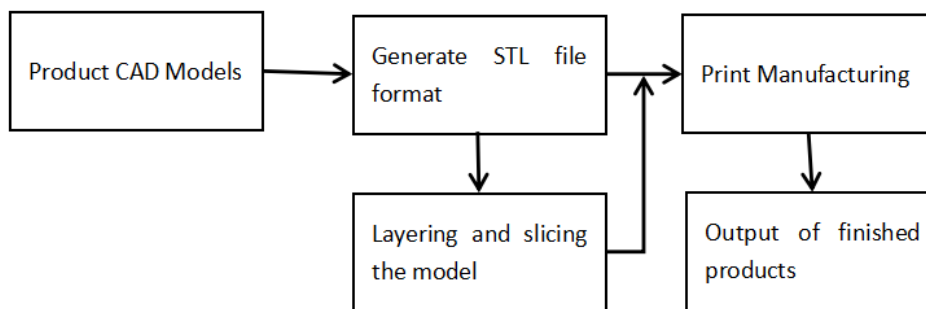


Figure 1. 3D Printing Process (Picture credit: Original)

2.2. Advantages of Printing Organs

(1) 3D bioprinting technology enables the simultaneous printing of cells and scaffold materials. This process not only ensures the orderly arrangement of cells in three-dimensional space but also enables a tight fusion between cells and scaffold materials, a fusion that can accelerate organ tissue repair and regeneration.

(2) The technology can design and print organs and organ tissues that meet individual needs according to the patient's specific situation. This achieves 'one person, one programme' precision treatment and increases the feasibility of personalised treatment.

(3) 3D bioprinting technology uses the patient's cells as the 'ink', combined with biocompatible scaffolding materials, to print organs with patient characteristics. The risk of rejection due to immunological differences is fundamentally eliminated.

(4) Doctors can observe, analyse and simulate the printed microstructure of tissues and their pathological processes to gain a deeper understanding of the development of diseases and the relationship between diseased tissues and their surrounding environment. This not only enables more precise surgical planning but also makes the surgical process safer and more controllable, improving the accuracy and success rate of surgery and bringing better treatment results and prognosis to patients.

(5) The cost of using 3D-printed organs has been reduced compared to traditional treatment modalities [4].

3. The Current Status of 3D Printed Organs

Within the field of medicine, 3D printing technology based on discrete-reconfiguration mechanisms is based on design models from computer software to print and manufacture tissues and organs through specific methods using biomaterials or living cells [5]. The process of 3D printing organs is shown in Fig. 2. In this article, the printed organs are classified as follows:

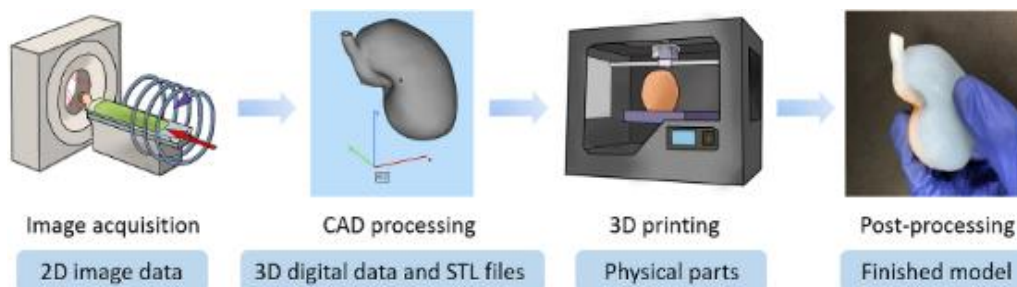


Figure 2. The process of 3D printing organs [6]

3.1. Printing of Soft Tissue Organs

Soft tissue refers to the human body's subcutaneous tissues, muscles, nerves, blood vessels, etc. 3D printing of soft tissue organs is to print biologically active soft tissue organs by using software that converts designed models into layer-by-layer printing commands, controlling the printer to use biomaterials (including alive cells) to print to a specified position.

For example, in Wu et al. [7] research on the printing of soft tissue organs, it was mentioned that in the human body soft tissues are characterised by good elasticity, they also mentioned the importance of the invention of flexible biomaterials with soft tissue mechanical properties for the repair and regeneration of this part. For example, hydrogels and biomedical elastomeric materials show huge applications in this field of engineering. In the research of Xu et al. [8], the use of light-cured printing was introduced to print the required soft tissue materials, which is also instructive for the development of soft tissue organ printing.

In the application of printed soft tissue organs, Li et al. [9] have two successful cases of using 3D printed soft tissue organs, they used vascularised free iliopsoas musculocutaneous flap and vascularised free peroneal musculocutaneous flap in combination with CAD/CAM and 3D printing technology respectively, to carry out the precise and individualised repair and reconstruction of composite hard and soft tissue defects after tumour resection, and the patients also achieved satisfactory effects after the surgery.

3.2. Printing of Hard Tissue Organs

Hard tissue organs are tissues in the human body that are hard and tough, mainly including bone and teeth. This part of the organ is printed in the same way as soft tissue is printed, but the materials used are very different. Since most of the bone plays the role of weight-bearing support in the human body, the materials used need to be highly rigid [10]. Examples include bioactive polymers [11] and bioactive ceramics [12]. This paper can learn from the study of Lu et al. [13] in white rabbits that both methacryloylated gelatin hydrogel scaffolds and bone marrow mesenchymal stem cells demonstrated their superiority as materials in bone tissue and accelerated the repair of bone defects in bone tissue engineering.

In addition to the materials mentioned above, the materials used are more varied due to the properties of teeth tissues such as high hardness and difficulty in self-repairing. In the study by Feng et al. [14], they chose to print with photosensitive resin and nylon. And in the study developed by Zeng et al. [15], the use of collagen-based materials was mentioned as a printing material. However, whatever the material used, at the current state of the art, printed dental tissue is still no substitute for native human teeth tissue. Nonetheless, the success rate of 3D-printed dental tissue in clinical applications is significantly higher than that of traditional methods. For example, in Wang et al.'s

study, both traditional and 3D printing were used to treat patients, and the result was that 3D printing had a higher success and retention rate [16].

3.3. Printing of Complex Organs

As shown in Fig. 3, complex organs are referred to in this article as organs that have fine anatomical structures and multicellular types and require a rich blood vessel network and innervation to maintain function. An example is the heart, one of the most important organs in the human body. Regarding this type of organ, the materials used for printing are much the same as the above two types of tissues and organs, but there are still no actual cases of clinical application. Through the research of Yang et al. [17], it can be learned that although 3D-printed hearts are not yet able to be transplanted, they can assist in guiding the treatment of many types of heart disease, reduce the related surgical risks, and improve the treatment effect. By printing out the corresponding model, this technology not only helps the surgeon to accurately select the size and specification of the valve during transcatheter aortic valve replacement surgery, which in turn effectively prevents the emergence of potential complications such as perivalvular leakage and coronary artery obstruction, thus improving the safety of the operation [18].

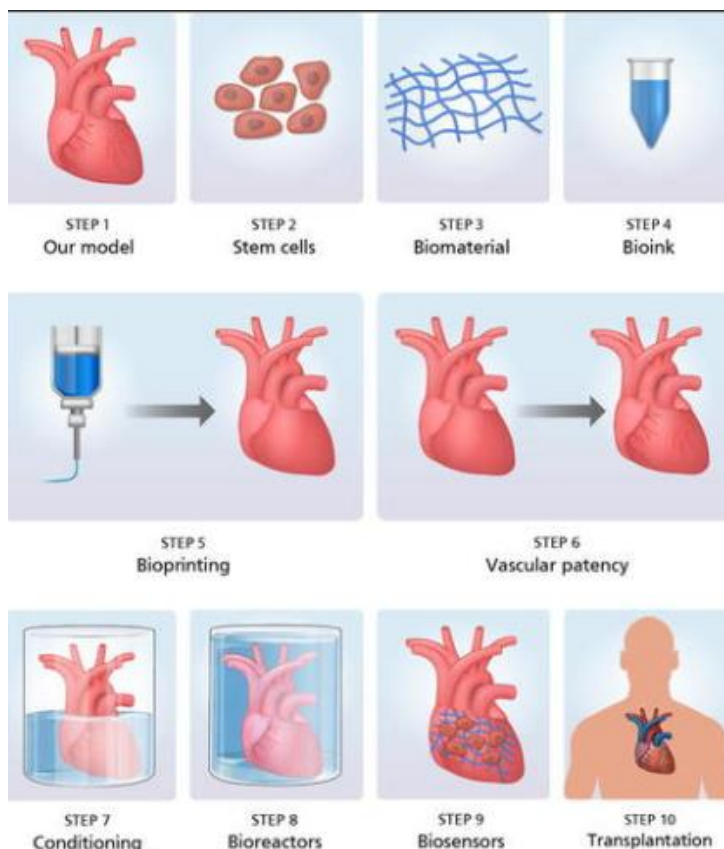


Figure 3. 3D Printed Heart Process [17]

In addition to the heart, the brain is also an extremely complex organ, according to Yan Y. This team of researchers from the University of Wisconsin-Madison and its partner institutions has successfully developed the world's first brain tissue made using 3D printing technology, which may be able to mimic the typical brain growth pattern and show similar functions, which is a significant milestone for the treatment of brain-related diseases [19]. A graphical summary of the study is shown in Fig. 4.

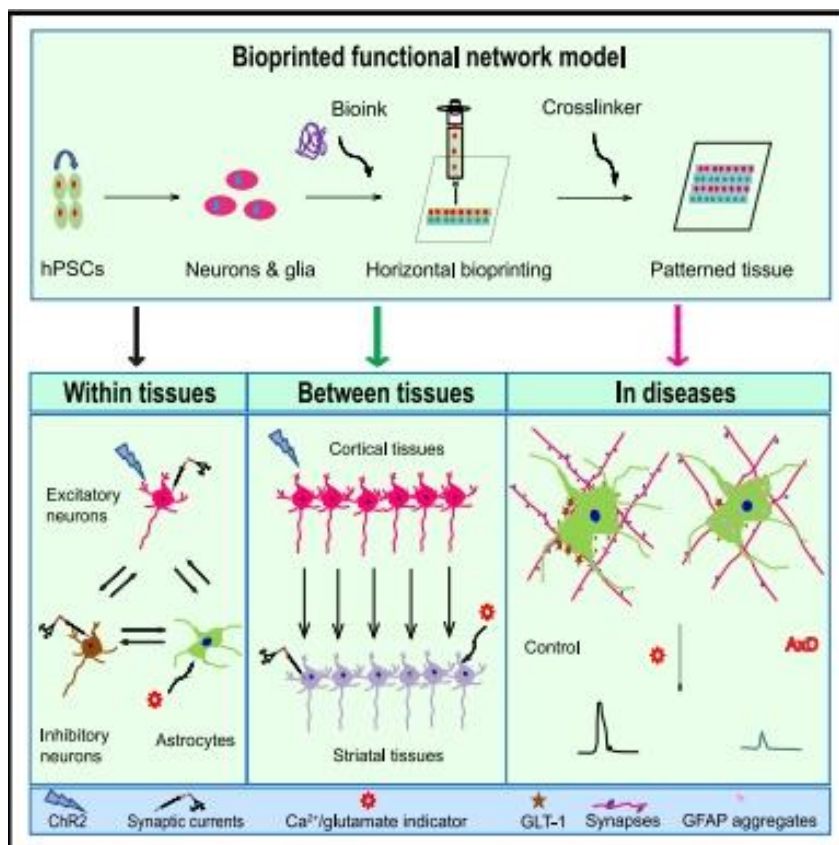


Figure 4. Bio-printed functional network model [19]

4. Outlook for 3D Printed Organs

The future is full of unlimited possibilities for 3D-printed organs as science with technology continue to advance. Here are some observations from this article.

4.1. Development and Application of New Materials

3D-printed organs will rely on more superior and diverse biomaterials. These materials not only need to be well-biocompatible and bioactive but also need to be able to mimic the mechanical properties and biological functions of natural tissues. For example, the development of biomaterials with self-repairing ability can continue to function after printing is completed, promoting tissue regeneration and repair. With the integration of nanotechnology and biotechnology, new nanomaterials, bioactive ceramics, and smart-responsive materials will also provide richer options for 3D-printed organs.

4.2. Multi-technology Integration and Application

3D printing technology will not be limited to a single printing process but will integrate a number of technologies to form a new application system. For example, the combination of biosensing technology or artificial intelligence technology and 3D printing technology, if the integration with biosensing technology, can be embedded in the printing process of biosensors, through which the sensor can be printed organ cell activity and metabolic levels and other parameters to observe, to facilitate the treatment can be carried out in a better way. If combined with artificial intelligence technology, it would allow AI to optimise the printing parameters or materials chosen through large data analysis, thus improving the accuracy of the printed organ. This will also improve the treatment of the organ.

4.3. Improvement of Legal and Ethical System

Organ printing may also cause a series of legal or ethical problems, so it is important to establish and improve the relevant regulations and ethical systems. This includes formulating clear laws and regulations on the printing, storage, distribution, and use of organs to ensure the legality and safety of the technology; at the same time, establishing an ethical review mechanism to protect patient privacy and ensure the moral acceptability of the technology.

The Government should expedite the formulation of laws and regulations for 3D-printed organs in this regard, to clarify the boundaries of the application of the technology and safeguard the rights and interests of patients and social security. It should also set up review organisations in the area of ethics to conduct strict ethical reviews of the research and development, testing, and clinical application of 3D-printed organs, to ensure that the technology is morally justified and that patient's private information is not leaked or abused in the process of organ printing.

5. Conclusion

This paper provides an in-depth look at the current state of 3D printing technology for organs. The definition and principles of 3D printing technology and the advantages of printing organs are clarified. After that, it also analyses and discusses the status of 3D-printed organs in three parts. In terms of soft tissue organs, such as skin and blood vessels, the printing technology has been more mature, and by precisely controlling the printing parameters and material selection, it is possible to print soft tissue organs with bioactive and mechanical properties. In terms of hard tissue organs, notably, the bone and dental tissues mentioned in the article, 3D printing has also yielded significant results, and although the printed teeth tissues are not yet able to completely replace native teeth, their success rate in clinical applications has been significantly higher than that of traditional methods. However, complex organs, such as the heart and brain tissues mentioned in the article, still present major challenges, especially in terms of clinical applications. It should be noted that this paper remains at the theoretical level and lacks specific experimental data and long-term tracking studies.

Finally, it is believed that with the research and development of new materials and the integration of cell therapy and biosensing technology, 3D printing technology can make greater breakthroughs in organ printing. It will make an important contribution to solving organ shortages and improving medical quality.

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