

# ***The Present Status of Research and Related Applications of Three-dimensional Printing in the Field of Healthcare***

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**Abstract:** As a new manufacturing technology, 3D printing technology has shown great potential in healthcare. The current study attempts to provide a comprehensive review of the current research landscape regarding the utilization of 3D printing technology in the healthcare sector. Nowadays, three-dimensional printing is applied in tissue engineering to manufacture complex and functionalized tissue scaffolds, hence providing strong support for regenerative medicine and enabling more precise tissue replacement in vivo. In the context of the manufacturing of medical models, the technology can reproduce with great accuracy the diseased organs or structures in question by the patient; in this respect, even bones are included. That gives intuitive physical models for surgical planning, simulation training, thereby improving the success rate of surgery and reducing complications. In the context of bespoke medical devices, 3D printing facilitates personalization of medical devices, such as prosthetics and implants, to a greater degree of fit for individual patient requirements. In the pharmaceutical sector, 3D printing technology is being employed to develop personalised medicines, with the objective of optimising drug release profiles in innovative ways. However, the application of 3D printing in healthcare also encounters obstacles, including the necessity to enhance the biocompatibility of the materials, achieve greater precision in printing, and establish more comprehensive standards and regulations. Nevertheless, the rapid development and wide spread of the use of 3D printing in health cannot be ruled out; more so, it is likely to change the face of healthcare in times to come.

**Keywords:** 3D printing, Medical Field, In vitro medical models, Personalised Therapy, Artificial organs and tissues

## **1. Introduction**

The rapid development and transformation of the manufacturing industry have been accompanied by the advent of 3D printing technology. This revolutionary manufacturing method gradually permeates the traditional manufacturing industry and is responsible for profound changes in the established pattern of production. 3D printing, also called Additive Manufacturing, is a process that involves the direct transformation of a digital model into a solid object by successive additions of material in layers, without the need for traditional molds or large production lines. This greatly enhances the efficiency and flexibility of manufacturing. Since its invention by Chuck Hull in 1986, 3D printing technology has undergone incredible changes from a relatively simple process to one that is truly highly complex.

Nowadays, it is considered an indispensable and important tool in different areas of manufacturing industries, healthcare, aerospace, and construction.

3D printing technology has been playing an important role in healthcare due to its unique manufacturing process and the great breadth of potential applications. Particularly, the technology has begun to make quite an effect in the healthcare sector through several means of printing, including:

Three-dimensional printing technology, especially processes like FDM and SLS, enables the fabrication of custom medical devices and implants with great detail. This is possible by replicating a patient's unique anatomical structure and clinical needs. These custom products range from prosthetics, orthotics, dental restorations, spinal implants, and artificial joints that enable greater precision in surgical procedures to allowing patients to recover much more quickly.

Secondly, 3D printing technology is also demonstrating its efficacy in the domain of surgical planning and simulation. Technologies such as stereolithography (SLA) and bonded inkjet can be employed to create accurate medical models based on patients' CT, MRI and other imaging data. These models will provide the physician with intuitive preoperative planning tools that enable more precise estimation of surgical difficulty, establishment of surgical plans, and surgical simulation, thus improving accuracy and safety during surgery while reducing the incidence of surgical risks and complications.

Moreover, bio-3D printing technology was one of the first applications in this area, and it has already illustrated the possibility of printing basic biological tissue structures, such as skin, blood vessels, and cartilage, by combining biomaterials, living cells, and advanced 3D printing technology, like inkjet and laser-assisted printing. This technology opens up new horizons for tissue repair and transplantation of organs, thus having a great potential in healthcare.

In addition to the above, 3D printing technology is also making a great contribution to medical education and training. The use of the printing methods mentioned above for the development of models in typical cases allows medical students to gain hands-on operative experiences in simulated surgical settings, thereby improving their surgical skills and endurance. Such models can also be used as teaching aids to help students understand human anatomy and principles of disease, thereby increasing the efficiency and effectiveness of medical education.

This paper will classify 3D printing based on the above-mentioned areas of 3D printing and explain its development in different fields with current developments in the medical application area.

## **2. Technical overview of 3D printing methods**

### **2.1. Fused deposition modelling (FDM)**

FDM is a technology of 3D printing with the involvement of thermoplastic materials. The technology makes use of thermoplastic materials, like polycarbonate and polypropylene, by melting through heating and thereafter depositing successive layers to form a full 3D object. Applications of FDM technology in printing complex shapes are realized at high precisions and speeds and hence stand among the most employed 3D printing techniques in the manufacturing industry.

### **2.2. Bioprinting**

Bioprinting is a category of 3D printing that was specifically designed for printing biological materials. Technology builds up layer by layer under pressure through the extrusion of biomaterials like collagen and cellulose, and finally constructs 3D objects with biological structures. Bioprinting has numerous applications in the biomedical field, which include but are not limited to the printing of human tissues and organs, a process that has revolutionized the field of medicine.

### **2.3. Selective laser sintering (SLS) and electron beam manufacturing (EBM)**

Both SLS and EBM are technologies that make use of high-energy beams—the laser or electron beams—which are used in melting powdered materials to construct three-dimensional objects. SLS uses a high-power laser beam to scan the powdered material, making it melt locally in the process of building layer by layer. On the other hand, EBM makes use of a high-power electron beam instead of a laser beam to complete the process. Both of these technologies are suitable for printing complex shapes at high printing accuracy and speed. Electron Beam Manufacturing is particularly effective at printing very high-strength, abrasive-resistant materials.

### **2.4. Stereolithography (SLA) and continuous liquid interface production (CLIP)**

Basically, both SLA and CLIP are technologies that make use of UV light for the curing of photopolymer resins in building 3D objects. SLA uses a UV laser beam that can selectively cure the photopolymer resins, thus enabling the layer-by-layer stacking of these materials until a complete 3D object is formed. In contrast, the CLIP technology uses UV light from the bottom of the resins to cure certain areas and raise the printing platform to create a continuous and efficient 3D printing process. Applications of both technologies are justified when printing an object requires great accuracy and details. As a result, they are widely utilized in production and prototyping.

### **2.5. Bonded inkjet/inkjet and polyjet**

Both Bonded Inkjet/Inkjet and Polyjet are technologies using inkjet technology to deposit liquid material in a selective manner onto a powder layer or onto a build platform, thereby enabling the construction of three-dimensional objects. Bonded inkjet technology uses a liquid bonding agent to bond layers of powder together in a successive manner, while Polyjet makes use of a photopolymer liquid as the print material, which is deposited and cured in a layer-by-layer fashion to create the intended 3D object. Both are suitable for complex structures and printing at high precisions, hence providing a greater avenue for manufacturing and prototyping.

### **2.6. Laminated manufacturing**

LOM is a technology used in the manufacture of three-dimensional objects by layers of bonded coating materials. With the help of this technology, the shape of the desired object is built layer by layer while continuously bonding and laser-cutting the layers of the bonded coating material. LOM technology could print out objects with complex structures with high precision, which is another effective three-dimensional printing method for manufacturing and prototyping.

## **3. 3D printing in the field of health care research status and specific applications**

### **3.1. Medical models**

In medical education and demonstration, the use of medical models has always been considered one of the key methods to promote teaching quality and improve understanding. Most studies in this area focus on the development of various medical models for mass teaching of numerous kinds of diseases, including rare diseases, and corresponding educational effects. Also, these models find their application in case studies and simulations relevant to the domain of clinical treatment.

Regarding medical education, Wan Cheol Kim and other scholars have been among the pioneers in conducting research into the integration of 3D printing technology-generated models into cardiology undergraduate medical education. They had skillfully integrated the high-precision 3D-printed model with detailed medical images to construct an intuitive and interactive learning

environment [1]. It was this new approach that significantly improved the level of knowledge and skills of medical students in such a complex anatomical structure of the heart, pathophysiological mechanisms, and surgical techniques. It is also inextricably combined with the current mainstream trend of surgical teaching toward high simulation and precision, providing a strong support for the innovation of the medical education model.

In addition to its use in the teaching of cardiology at the undergraduate level, 3D printing technology has demonstrated a diverse range of potential applications in the fields of anatomy research and teaching, organ structure teaching, and stomatology, as well as other areas of medical education. 3D-printed models boast of their precision and life-like detail; thus, they are one of the most important tools to be used by medical students in enhancing their learning regarding the structure and function of the human body, thereby optimizing their clinical proficiency. These models could not only help integrate theoretical knowledge and practical procedures comprehensively but also provide students with a training platform that resembles real clinical scenarios, thereby significantly raising the quality and effectiveness of medical education.

It also displays unique advantages in the field of clinical treatment and case analysis. High accuracy and fidelity of printing allow medical models to be printed and fully express the real condition of the patient, thus providing doctors with a powerful auxiliary tool. For instance, Runze Liu and other scholars used the construction of 3D printed models and advanced ultrasound positioning technology [2]. The combination of neurogenic bladder, abnormalities in the pelvic structure, and 3D printing technology allows for an effective review of the treatment outcome properly. The results reflect the effectiveness of applying the 3D model measurement in patients with neurogenic bladder and pelvic structural abnormalities. It was found that the measurements from the 3D model had only a little discrepancy with the actual treatment. This study not only provides clinicians with an effective and precise assessment tool but also helps establish a scientific basis for the development of personalized and accurate treatment plans, further advancing the cause of precision and personalization in clinical medicine.

Moreover, 3D printing technology is a very important contributing factor for personalization in patient treatment. For instance, a research team led by Hidemasa Takao used 3D printing technology to replicate and simulate a patient's hollow model of the splenic aneurysm before surgery of the splenic aneurysm [3]. The application of this technology allowed the medical practitioner to practice in-depth analysis and come up with a treatment plan suitable for aneurysms of different patients, hence facilitating the building of a more correct and safe treatment strategy for each patient's case. This application not only improves the accuracy and safety of the surgery but also offers an opportunity for the patient to receive a more personalized and efficient mode of treatment. This is a full demonstration of the potential and the enormous effect of applying 3D printing technology in the field of medicine.

In the end, 3D printing technology has been applied in the fields of medical education, clinical treatment, and personalized care for patients. It has made a revolutionary change to the medical field and has also given firm support to the improvement in quality and progress of medical science and technology.

### **3.2. Personalised medical devices and implants**

Nowadays, three-dimensional printing technology has distinctive capabilities in the manufacturing domain, as well as in the realms of personalized customisation and bespoke production. Specifically speaking, it will be used for bespoke surgical guides, implants, post-operative protection devices and rehabilitation therapy aids, among which a stent is one of the most important medical implants used in cardiovascular, orthopaedic and many other specialties. The use of personalized stents manufactured through 3D printing technology may greatly raise the success rate of surgeries and

recoveries. Combining high-precision digital modeling with advanced printing processes, 3D printing technology has been able to achieve the accurate customization of medical stents. This has been highly beneficial in improving surgical precision and therapeutic effects, solidly underpinning the fast postoperative recovery of patients. The research will focus on creating guidelines and rehabilitation tools for different types of surgery, the refinement and innovation of scaffolds, making implants and surgical guides that are conducive to the human body, and the efficacy of treatment will be improved.

In the field of orthopaedic surgery, the application of three-dimensional printing technology has extended from the original development of its use in bone repair to a wider range of applications, including complex and delicate plastic surgery, articular replacement, prosthetic manufacturing, and other closely related fields. For example, cleft lip and palate deformities of infants are an important part of plastic surgery. A number of studies found that a silicone impression of the cleft, obtained in the awake child, was then converted to a plaster model that, using digital technology, resulted in a digital model 2 mm thick. This was then 3D printed using biocompatible resin materials, and a personalized plastic plate was made through a series of post-processing steps-including removal of the support, polishing, and installation of wire fixtures [4]. Such scaffolds can not only effectively improve the morphology of the fissure but also greatly enhance the recovery of oral function, thus opening an absolutely new direction in treatment for infantile maxillofacial deformities and demonstrating huge potential for using 3D printing technology in complex plastic surgery.

The introduction of 3D printing technology has brought about a revolution into the field of dentistry. The use of 3D printing is being applied to almost all dental treatments, from dental restorations to orthodontic appliances and dental implants, among other dental aids. To illustrate, the advancement of material science has furnished a more expansive array of options for personalisation through 3D printing technology in the domain of dental scaffolds and restorations. In particular, dental restorations prepared using lithium silicate for ceramic 3D printing and combined with the sol-gel method not only exhibit excellent translucency, but also achieve a precise match with the patient's tooth morphology and colour [5]. This type of restoration can meet not only the demands of patients in dental function but also an unprecedentedly high level aesthetically, thus introducing a brand-new treatment concept and means into dental restoration.

In cardiovascular disease management, the advantages of three-dimensional printing technology are also prominent. In this respect, three-dimensional printing technology plays an epoch-making role in cardiovascular disease surgery, such as transcatheter aortic valve replacement, left heart ear blocking, and other auxiliary interventional procedures. The vascular scaffolds obtained by means of 3D printing technology can accurately present a model of the morphology and structure of the patient's blood vessels, which significantly increases the effectiveness of the intervention while at the same time reduces complications. In the study by Muhammad Amir Khan et al., for instance, personalized design and precision manufacturing of 3D printed stents in percutaneous coronary intervention and other procedures offers doctors a much more accurate therapeutic tool[6]. These 3D-printed stents have the purpose of minimizing the occurrence of post-procedural restenosis, thrombosis, and neoplastic endothelial growth by their precise design and because they are made of biocompatible materials. The stent also allows for a better outcome for the patients. This is because they allow for recovery and functional reconstruction of the diseased site through their mechanical support and the prevention of hyperplasia. 3D printing technology can be used to more effectively fight against coronary artery disease and other cardiovascular diseases, with the potential to revolutionize the treatment of cardiovascular disease.

Another thing that is remarkable about 3D printing technology is its efficacy in regenerating and repairing damaged skin and nerves: the placing of scaffolds around damaged skin or nerve tissues helps in the repair of such damages. Amir Mohammad Danesh Pajooh proposed that a bionic scaffold,

fabricated by combining 3D printing and electrostatic spinning technology, may serve as a means for the repair of wounded skin tissue [7]. The design of this scaffold is very innovative, with a top layer composed of dextran vascular endothelial growth factor using 3D printing technology. Electrostatic spinning technology can weave the bottom layer into nanofibres of gelatin-keratin with the purpose of guiding cells to effectively attach. Its bilayer structure can ensure biological activity and improve the structural stability. This scaffold is expected to effectively raise the efficacy of implantation and expedite the process of tissue repair. 3D printing technology was used by Chong Chen and coworkers in the neurology department to fabricate interferon gamma-pretreated neural stem cell-derived exosomes with collagen and chitosan composite bioscaffolds. This new strategy represents a potentially active therapeutic approach and pathway for neurological function restoration after traumatic brain injury. Low-temperature 3D printing technology enabled the combination of IFN-Exo with collagen/chitosan successfully. This method effectively preserved the bioactivity of exosomes [8]. The biomaterial scaffold mounting enhanced stability and retention effects of exosomes but also made sure that their therapeutic potential could be explored to the fullest. In turn, it guaranteed that the exosomes could play a continuous role at the injury site for the general purpose of long-term repair and regeneration. This application not only expands the scope of 3D printing technology in the medical field but also brings new hopes and possibilities for the rehabilitation of nerve injury patients.

### 3.3. Personalised drug preparation

The application of three-dimensional printing technology in the pharmaceutical field has undoubtedly demonstrated revolutionary potential unprecedented in depth. It is true that, with this high-precision layer-stacking manufacturing process, drugs are able to realize complex and variable external morphologies and a fine internal micro-architecture with unprecedented precision. Such precise control over the structure of drugs allows for precise regulation of drug release behavior, too, thereby offering immense scope for the optimization of drug action.

Speaking of types of drugs, either old-fashioned tablets or gels to complicated personalized drug design, 3D printing technology has shown a strong capacity in preparation. Of them, representative 3D printing techniques, including hot-melt extrusion deposition, semisolid extrusion, fused deposition moulding, powder bonding, selective laser sintering, and stereolithography, each technique has its own merits and defects and is suitable for different types of preparation of drugs [9]. 3D printing techniques for drug preparation would be selected based on the specific drug preparation conditions and personalized treatment for the patients.

The current direction of research in personalized drugs is the development of complex drug formulations and configurations in the context of customized therapy. Mohammed S. Algahtani's research shows the capabilities of the 3D printing technique and the method of extrusion for the development of complex formulations [10]. To this day, it has prepared capsule and nano injections successfully. The absorption effect in the human body produced by capsules is highly specific due to the unique composition of the capsule. Drugs in such a configuration would have very strong targeting properties; this gives big support to personalised treatment and subsequent studies. Simultaneously, in personalized therapy, the importance of the conformation of drugs is being gradually brought into prominence. The way a particular drug is formulated can greatly affect the stages of a disease in a patient and, thus, can affect the drug's absorption. Studies have demonstrated that the use of 3D printing technology to create drugs in different shapes, such as disc-shaped and donut-shaped acetaminophen oral drugs, allows for the customisation of drug release profiles to align with the specific therapeutic needs of patients at different times [11].

Additionally, 3D printing technology has overcome the limitation of multiple drugs that could not coexist in one formulation and thus opened new ways for the preparation of compounded

formulations. For instance, in one of the works, Paola Zgouro et al. managed to prepare three different antihypertensive drugs (diltiazem, propranolol, and hydrochlorothiazide) as hollow ring tablets using the techniques of HME and FDM [12]. The composite formulation exhibited excellent aggregation, adhesion, and retention in the porcine stomach along with sustained drug release. This further reinforces the potential of additional research in the field of personalised therapy.

In a word, 3D printing technology is used in the pharmaceutical field not only to promote drug preparation methods and the design of drug configurations, but also to promote personalized therapy and the digital transformation and intelligent advancement of research and development.

### 3.4. Human Tissues and Organs

As a pioneering and highly innovative biomedical manufacturing technology, three-dimensional printing of human tissues and organs is gradually showing its considerable potential and extensive application prospect in the medical field. With a quite painstaking layer-by-layer deposition process, this technology is able to precisely build complex and fully functional models of human tissues and organs by using the layered structures made from biomaterials. To realize this, the main building blocks of the printing process—living cells, bioactive molecules, and other biomaterials—are integrated skillfully into the printing system. This is done in an effort to replicate at least the microstructure and physiological properties of natural human tissues as closely as possible.

In the field of tissue engineering, 3D printing provides a new methodology for tissue repair and regeneration. Also, it has developed a new concept of personalized medicine. Through better control of printing parameters and the composition of the bio-ink, researchers will be able to tailor the preparation of tissue models, resulting in high compatibility with the patient's own tissues and thereby greatly improving therapeutic efficacy and quality of life. Besides, 3D printing technology has its own specific advantages in drug screening and disease modeling. By printing the tissue models with predetermined pathological features, researchers can more accurately simulate the processes of diseases and provide valuable insights into drug development and treatment plan optimization.

In the 3D printing of human tissues and organs, choice of bioink bears great consequences because it can affect the fundamental characteristics of the printed tissues and organs. Bioinks so far have been primarily water-based gels or cell aggregates. These contain cells as the basic structural units, besides incorporating growth factors, biocompatible polymers, and other components to mimic the complex structure and function of human tissues. In the process of continuous research development, more research groups are developing various types of bioinks for improving printing performance and their biocompatibility.

The development of 3D-printed products for different tissues with corresponding bioinks in human tissue repair is one of the most active areas of interest in this field. For instance, it has been shown that the use of 3D printing technology in the creation of artificial vascular networks can overcome the problem of vascular networks in engineered tissues lacking [13]. Due to this finding, proper channels for nutrient and oxygen delivery in tissue regeneration are established, and a sound basis for the building of tissues and organs with complete physiological functions was attained. Furthermore, the utilisation of 3D printing technology in the construction of intricate vascular networks within the human body has also garnered significant interest, with the potential to bring about a transformative advancement in the domain of tissue engineering.

Printing human organs requires the use of more refined and highly biocompatible bioinks. The technology for printing complex organs like the heart is still incomplete, and current research is still focused on printing simple organs. In a study conducted by Suihong Liu, the researchers were able to successfully achieve endothelial germination and interconnected vascular network formation within 3D-printed scaffolds by preparing composite bioinks enriched with vascular support proteins [14]. This discovery not only provides the possibility of printing organs with a complete vascular system,

but also establishes an important foundation for improving the survival rate and functional recovery of printed organs. As research and development of the bioinks continue deepening and 3D printing technology improves, it is reasonable to expect more contribution of 3D printing of human tissues and organs to achieve large breakthroughs and innovations in the field of medicine.

## **4. Limitations of 3D printing and the future**

### **4.1. Technical and material limitations**

One of the major concerns and challenges of using 3D printing in medical areas is that the technology inherently possesses several technological and material limitations. For instance, there are only a few numbers of biomedical materials available for 3D printing. Additionally, these materials often do not satisfy the complex biomechanical or biocompatibility requirements arising from medical applications. For example, some printing materials cannot yield good reproductions of some real physical properties of native human tissues, such as elasticity and hardness. This may result in printed medical products that cannot function optimally in clinical settings. In addition, the category of biocompatible materials suitable for 3D printing is limited, and their cost is high; this significantly restricts large-scale use of 3D printing technology in the medical field. Especially when mass production or application in low-income areas is required, material cost becomes a great challenge.

### **4.2. Cost and efficiency issues**

These medical applications of 3D printing techniques pose cost and efficiency issues. First, the initial investment in 3D printing equipment is considerably high. This is in its purchase price, installation costs, commissioning, and after-sales maintenance costs. This can be a significant challenge for institutions that have relatively lower financial allocations within them. The process of 3D printing is sometimes quite time-consuming for specific cases when dealing with complicated structures or when high-precision printing is required. This makes certain emergency medical situations suffer due to the shortage of time for taking care of such patients. Therefore, the urgency of improving the efficiency and reducing the cost of 3D printing are issues that await an immediate solution.

### **4.3. Data processing and accuracy control challenges**

Most applications require the availability of accurate digital models as input for 3D printing. In the case of medical applications, however, securing good-quality patient data has become an important challenge. First, medical data require intensive processing before they can be prepared for making models that will be used in 3D printing. This requires a great amount of technical expertise and also possibly leads to a few data errors that may have a direct consequence on the final printed product's accuracy. The layer-by-layer build-up during 3D printing may lead to subtle deviations, even in the case of high accuracy of data model conversion, especially in structures that are complex or minute in detail. These deviations can influence the function and fit of medical products, which might be an important issue in medical applications, if there is the need for precise matching of patient anatomy.

## **5. Conclusion**

As a disruptive manufacturing technology, 3D printing is gradually demonstrating its considerable potential and extensive application prospects in the field of healthcare. In this study, one could say that in all aspects of the creation of custom-designed medical devices and implants, surgical planning, biological tissues and organ printing, formulation of drugs, medical education, and training-the 3D printing technology has not only attained remarkable success but also taken the innovation and development pace of the healthcare industry to a whole new level.

Personalized medical devices and implants are among the most intuitive applications of 3D printing technology in healthcare. 3D printing technology creates highly customized products by accurately reproducing a patient's anatomy, hence improving the accuracy of surgery and patient recovery. Besides, 3D-printed medical models in surgical planning and simulation provide intuitive preoperative tools that reduce surgical risks and complications to a great extent.

In the field of printing biological tissues and organs, 3D printing technology has shown its revolutionary potential. Mixing biomaterials with living cells has so far enabled successful prints of highly varied biological tissues, allowing for new solutions for both tissue repair and organ transplantation. It is envisioned that advances in this field will not only meet the demand due to organ shortage but could lead to new therapies that will benefit the patients.

Meanwhile, 3D printing technology utilized in the preparation of pharmaceuticals offers new insights into the possibility of personalized therapeutic intervention. Controlling the external morphology and internal micro-architecture of drugs with high precision can be afforded by 3D printing technology for achieving an accurate regulation of drug release behavior, improving drug efficacy, and reducing side effects.

In addition, 3D printing technology can be used in medical education and training. By establishing models of typical cases, medical students can carry out practical operations in a simulated environment and thus enhance their surgical skills and endurance. Therefore, it not only enhances the quality of medical education but also is very supportive for the cultivation of more exemplary medical professionals.

In the future, as the 3D printing technology continues to advance and its cost gets further reduced, its application within the healthcare sector will be broadened. 3D printing technology will continue to power innovation and advancement in the healthcare industry and contribute more greatly to the advancement of human health.

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