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3D printing technology and its application in the medical field

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Abstract

3D printing technology is a rapidly emerging new digital manufacturing technology. Because of its advantages of design freedom, mass customization, and rapid prototyping, it has broad application prospects in the fields of medicine, aerospace, automobiles, and food. With the increase in demand for precision and personalized medical care, 3D printing technology is gradually being applied to medical fields, such as implant manufacturing, diagnostic platforms, and drug delivery systems, and has become one of the more cutting-edge research fields. Its personalized The customized features enable 3D printing technology to prepare corresponding medical products according to the patient's condition to help patients recover. Therefore, this article outlines the development of 3D printing technology, classifies and introduces the medical materials that can be used for 3D printing, and the application of 3D printing technology in the medical field. However, 3D printed implants are static and inanimate, and cannot be adapted to the changes in the internal environment. 4D printing can produce "active" and more complex structures that are very similar to natural tissue structures. The engineered organization structure inherits the advantages of 3D printing technology and at the same time makes up for some of the shortcomings of the existing 3D printing. It will have a broader application prospect in the medical field in the future.

Keywords

3D printing; medical materials; implant manufacturing.

1. Introduction

3D printing, also known as additive manufacturing, is a technology that uses bonding materials such as powdered metals or plastics to manufacture products with multi-level structures or complex geometric shapes based on three-dimensional model data. As a new type of molding technology with rapid development and great potential, 3D printing technology has a wide range of applications in the fields of medicine, aerospace, automobile and food. For example, 3D printing knee meniscus and heart valves, the Chang'e-4 satellite is equipped with multiple 3D printing aluminum alloy components, 3D printing low-speed electric cars, 3D printing candy, chocolate, sushi, etc. In addition, in the field of cultural heritage protection and restoration, there are also 3D printing technologies. For example, researchers at the Maidstone Museum in the United Kingdom used 3D printing technology to reshape the face of a mummy 2,500 years ago.

Although 3D printing technology has a wide range of applications, it is currently widely used in the field of biomedicine. In 1993, the Massachusetts Institute of Technology obtained a patent for 3D printing technology based on the principle of inkjet printing. Since then, MIT has been at the forefront

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of biological 3D printing technology. Foreign researchers in this field include the Zurich Federal Institute of Technology and the University of California, Los Angeles. Branch school and so on.

2. 3D printing technology principle and classification

The core principle of 3D printing technology is "layered manufacturing, layer by layer". The printing process is mainly divided into 5 parts: one is design, which uses computer-aided design software to design digital 3D printing objects; the other is to save and save the designed 3D. The printing objects are saved in a file format readable by a 3D printer. Common common file formats include stereolithography files and virtual reality modeling languages; the third is import, and the saved files are imported into the 3D printer; the fourth is printing, based on the characteristics of raw materials. As well as product requirements, select the appropriate filament, set the printing temperature, speed and pressure and other related parameters; fifth is post-processing, the surface of the product is processed after printing. As a rapid prototyping technology, a 3D printer can complete the entire manufacturing process, and the process is more simplified. 3D printing technology is suitable for the production of small batches of products with complex structures. Traditional manufacturing methods focus on the production of large-scale and mass-produced parts. Therefore, 3D printing technology and traditional manufacturing technology can complement each other and jointly promote modern manufacturing to smart Transformation of globalization, digitization and networked manufacturing.

3. 3D printing medical materials

Although the human body has strong regenerative capacity, the regenerative capacity of different tissues is not the same. The regenerative ability of cells is affected by factors such as tissue type, growth hormone and physical size. Once tissue damage exceeds its self-repair limit, external support is needed to help it complete the repair process. The method of external intervention to support tissue regeneration is generally called tissue engineering. The construction of tissue engineering artificial organs requires three elements, namely seed cells, scaffold materials and cell growth factors. As one of the three elements of tissue engineering, scaffold materials need to have good biocompatibility and certain mechanical strength, and their internal structure Will affect cell viability and cell proliferation. Patients have different conditions, and stents with different structures need to be customized according to specific conditions. Traditional manufacturing methods are difficult to meet this personalized customization requirement. The emergence of 3D printing technology has brought good news to patients. It can provide personalized customized services, manufacture stents with complex structures, and greatly improve the performance of stents. Medical materials used for 3D printing need to have good biocompatibility, controllable degradation rate, and morphologically similar to tissues in the body. According to the chemical properties of the materials, medical materials used for 3D printing are roughly classified into metals, ceramics, and polymers.

3.1 Metal-based biomaterials

Metal-based biomaterials mainly include titanium-based metal biomaterials and cobalt-based metal biomaterials. Metal biomaterials are widely used in the field of biomedicine due to their excellent biocompatibility, fatigue resistance, corrosion resistance and high specific strength. When metal biomaterials are used as load-bearing implants, they need to establish a perfect combination with human tissues. Preliminary studies have shown that, as time goes by, Ti-based metal biomaterials may be surrounded by a hard tissue layer, restricting its function; in addition, due to the stress shielding effect, the traditional Ti64 implants do not match the mechanical properties of human bones. . Using 3D printing technology Ti-based metal biomaterials for surface modification can not only improve their surface wear properties, but also create porous and hierarchical structures to enhance osseointegration.

Although 3D printed titanium-based metal implants are one of the most widely used implants, the stress shielding effect caused by the mismatch between its Young's modulus and the Young's modulus of bones is currently the mainstay of titanium-based metal materials. One of the problems. In the

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future, it is still necessary to explore more titanium-based metal material processing strategies, and develop a new type of medical titanium-based metal material with good biocompatibility and better comprehensive performance, so as to effectively enhance the osseointegration ability of the 3D printing stent.

Cobalt-based metal biomaterials have high strength and wear resistance. In the medical field, they are mainly used to prepare load-bearing implants, dental implants, and auxiliary tools in plastic surgery and reconstruction operations. The high rigidity of Co-based metal biomaterials is easy to cause stress shielding effect, which limits its application in the field of biomedicine.

3.2 Bioceramic materials

The history of bioceramic materials in 3D printing applications is relatively short, and the main reason for limiting its application is that the processing of bioceramics is relatively difficult. Bioceramic materials are generally used to prepare teeth and bone implants. The use of 3D printing technology to produce higher precision bioceramic teeth and bone implants can meet the special needs of patients for bone and tooth replacement. Currently, the most commonly used bioceramic materials are calcium phosphate and bioactive glass). The composition of ceramics is similar to that of natural bones and teeth. It has excellent biocompatibility and is a widely used bioceramic material. The porous block tricalcium phosphate and hydroxyapatite were prepared by 3D printing technology, filled into the titanium hemisphere, and implanted in the sheep. After taking it out, the amount of new bone in the test is 1.8 times that of the titanium hemisphere filled with granular bovine bone and granular tricalcium phosphate. Compared with existing bone substitutes, the implantation of porous massive tricalcium phosphate and hydroxyapatite in the sheep skull model can enhance vertical bone growth, and its controlled porous structure can promote the formation of more bone in the bone bed, indicating This kind of scaffold can effectively promote the bone synthesis process.

Surface modification of MBG scaffold can further enhance its biological performance. The MBG-β-TCP scaffold can enhance the ability of new bone formation in the body and the attachment of human umbilical vein endothelial cells, which significantly enhances the expression of angiogenesis genes. It shows that the 3D printing scaffold modified with MBG nanolayer can effectively improve the biological performance of the scaffold, which is a new strategy to improve the bone formation in the scaffold. Although BG has good biological activity and osteoconductivity, the inherent fragility of BG limits its application in clinical medicine. By incorporating other biodegradable polymers into BG materials to prepare BG composite materials, its performance can be effectively improved to meet broader application requirements.

3.3 Natural polymer

Natural polymers, such as chitosan, polylactic acid and hyaluronic acid, have good biocompatibility and biodegradability, and can avoid immunogenic reactions when used in organisms, so they are widely used in tissue engineering and Regenerative medicine.

3.3.1 Chitosan

Chitosan is a natural polymer with good biodegradability, biocompatibility and renewability. The amino groups on the chitosan chain are soluble after protonation, and soluble chitosan is widely used, such as the preparation of TE stents, biosensors, and drug delivery. In previous studies, it has been confirmed that the inflammatory response is critical in tissue repair, and the malignant inflammatory response may lead to immune rejection of the implant. Therefore, when choosing an implant, it is necessary to take the possible inflammatory response into consideration. The experimental results show that the chitosan scaffold has a larger pore structure, which can significantly promote the secretion of pro-inflammatory cytokines, thereby inhibiting some possible inflammatory reactions, indicating that the appropriate surface characteristics and geometry are selected when manufacturing the implant scaffold The biological material is crucial.

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3.3.2 Polylactic acid

Polylactic acid is a natural polymer with excellent mechanical properties, degradability and biocompatibility, and is widely used in tissue engineering, drug delivery and wound healing. PLA can be hydrolyzed and degraded by ester bonds without enzymatic catalysis, and the degradation product lactic acid is a substance in the body's metabolic cycle, making PLA one of the most potential raw materials in the field of 3D bioprinting.

3.3.3 Hyaluronic acid

Hyaluronic acid is a natural glycosaminoglycan widely found in connective tissues, epithelial tissues and nerve tissues. Because of its natural viscoelasticity, biodegradability and biocompatibility, it is considered an ideal bone tissue Engineering support materials. Using bio-ink based on methacrylated hyaluronic acid as raw material, cartilage models with different chondrocyte densities were prepared using stereo light curing molding technology. Studies have shown that cartilage differentiation mode is affected by cell density. High cell density can enhance the typical band-like segmentation of cartilage. Chondrocytes that form extracellular matrix are mainly distributed on the surface area, but there are also a small amount in the deeper area near the carrier membrane. The in vitro cartilage model printed by HAMA can be used for the treatment of articular cartilage defects.

3.4 Synthetic polymer

3D printed medical stents will eventually be applied to the human body, so biocompatibility is the basic requirement for a material to be suitable for implants. In addition, the implant material must be free of cytotoxicity, mutagenicity, carcinogenicity, and not cause allergies. At present, there are few types of synthetic polymers that can be used in the medical field, mainly focusing on biocompatible synthetic polymers such as hydrogels, polycaprolactone and polyetheretherketone.

3.4.1 Polycaprolactone

Polycaprolactone is a common polymer with excellent biocompatibility and biodegradability. Due to the hydrolysis of ester bonds, PCL can be slowly degraded in human body fluids, and the complete degradation products are carbon dioxide and water. In addition, due to its excellent processing performance, it has a wide range of applications in the field of 3D printing.

A functionally graded scaffold (FGS) was prepared using 3D printing technology. The obtained FGS has controllable porosity, biodegradability and certain mechanical strength. The FGS was implanted into the bone tunnel drilled in the femoral neck and head of the rabbit, and 8 weeks after implantation, it was taken out. It showed that the new bone on the FGS scaffold was ingrown and the bone containing bone marrow was formed. It was verified that the FGS scaffold was used for early treatment. The possibility of femoral head necrosis.

3.4.2 Hydrogel

The high water content and mechanical characteristics of the hydrogel are similar to those of natural extracellular matrix, so the hydrogel scaffold can be used to simulate the cell environment in vivo and help establish the connection between cells and between cells and extracellular matrix. In the 3D printing molding method based on extruded hydrogel, the requirements for the viscosity of the material are stricter. When extruding, the material needs a low viscosity to be extruded, and when it is deposited, the viscosity of the material must be high enough to prevent the material from dispersing during the gel, and the mechanical properties of the hydrogel cannot change over time during the cell culture process . Although the existing 3D printing technology can meet these requirements by adjusting the materials, this process is often at the expense of cell viability[48] In view of this, scholars have made many attempts on hydrogels in order to break the current situation. There are limitations.

4. 3D printing application in the medical field

As a rapidly emerging technology, 3D printing has been expanding its application in the medical field. The application of 3D printing technology in the medical field has mainly gone through the following

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stages: the first stage is the preparation of patient-specific anatomical models and anatomical manipulation aids; the second stage is the preparation of personalized specific implants. It is loaded with active substances (such as growth factors and drugs); the third stage is the manufacture of bones, cartilage, ligaments, meniscus and other structures; the fourth stage is the assembly of tissue components and individually printed implants to play a role. At present, in the medical field, 3D printing technology is mainly used in the preparation of orthopedic implants, skin substitutes, nerve repair, printing ovaries, and drug release.

4.1 Orthopedics

There are many successful cases of 3D printing technology in the clinical application of orthopedics. In 2018, Chinese doctors have successfully performed the first 3D printed proximal humeral prosthesis surgery, 3D printed osteotomy tools assisted knee replacement surgery, 3D printed artificial cervical vertebral body implantation and other operations. Come new hope.

4.2 Skin

The skin is the body's barrier to the external environment and is of great significance to the survival of organisms. As an important tool to promote wound healing, skin substitutes have been widely used in the treatment of patient wounds for a long time. There are many problems with skin substitutes manufactured by traditional methods, such as insufficient bionics performance, high production cost, single size, and long preparation time. Therefore, people urgently need a technology that can realize low-cost, standardized manufacturing of skin substitutes. The emergence of 3D printing technology provides a feasible solution to this problem.

4.3 Peripheral nerve repair

The nerve conduit can connect two nerve endings, guide the regeneration of axons, and provide a nutrient environment for the aggregation and proliferation of Schwann cells. To manufacture nerve catheters with excellent performance, two issues need to be considered: one is the choice of raw materials, and the other is surface modification and stent manufacturing. The prepared nerve conduit should meet the following requirements. One is that it can connect to the defective nerve; the other is that it can provide a stable environment for axon regeneration; and the third is that after the damaged nerve is successfully connected, the nerve conduit can be effectively degraded to further improve the nerve. Provide space for growth. The functional nerve repair stent can release related drugs to accelerate the repair process while giving space to the nerve to recover.

4.4 3D printing ovary

The ovary is located in the female pelvic cavity. Its main function is to produce and discharge egg cells and secrete sex hormones to promote the development of female sexual characteristics and maintain their normal activities. If there is a problem with the ovaries, it will lead to female infertility and affect the health of the patient. The microporous hydrogel scaffolds with pores of different geometric shapes were fabricated using 3D printing technology, and the support of the scaffolds to ovarian follicle cells was explored respectively. Experimental results show that with the increase in interactions within the stent, the diffusion of follicular cells is limited and the survival rate increases, and the stent becomes highly vascularized. In addition, without the use of exogenous angiogenic factors, the bioprosthetic ovaries become vascularized one week after implantation. The researchers then implanted it into mice with ovarian defects and found that their ovarian function was fully restored and pups were produced through natural mating.

4.5 Drug release

3D printing tablets can achieve controlled release of drugs, and patients can flexibly change the intake of drugs according to their physical conditions. And in the use of narrow therapeutic index drugs, 3D printing technology provides a method of manufacturing tablets containing precise doses of drugs, which can reduce the potential risks caused by dose changes and medication errors.

At present, 3D printing can be done directly with drugs as raw materials, which can avoid the impact of carrier instability and variable drug loading on the therapeutic effect.

5. Future development trend

In recent years, 3D printing technology has been successfully applied in the medical field, and has played a key role in the prevention and treatment of some diseases that require implant transplantation.

The characteristics of personalization and customization make it closer to the needs of patients and provide a solid foundation for establishing a good bond between human tissues and implants. Compared with the traditional implant manufacturing process, 3D printing technology has significant advantages such as faster speed, lower cost, better biocompatibility and less inflammatory response. Although the emergence of 3D printing has greatly changed the technological status quo in the biomedical field and other industries, there are still some problems with 3D printing. The 3D molded implant is static and inanimate. Therefore, when implants are transplanted into the body, they cannot make relevant adaptive adjustments according to changes in the internal environment, and therefore cannot achieve the desired therapeutic effect; 3D printed cell-related products cannot be differentiated according to external stimuli, and routinely The 3D printing process will have a certain impact on cell viability. Although there are related studies that show that adding hydrazone compounds to hydrogels can not affect the cell activity encapsulated in them, at present this kind of exploration has only been carried out in vitro experiments.

According to the research status of 3D printing in the medical field, the main factor limiting the further development of 3D printing technology is 3D printing materials. The currently used solid medical materials mainly come from the composite modification of metal-based materials, hydrogels, calcium phosphate and other existing materials. The characteristic of these traditional solid material 3D printing products is that they are formed at one time and hardly change due to environmental changes.

Based on this, 4D printing technology emerged. Initially, 4D printing was regarded as "3D printing + time". With the continuous deepening of research, the definition of 4D printing has gradually improved. The currently generally accepted theory is: when the 3D printing structure is stimulated by a predetermined, its properties and functions will change. Change with time. Common stimuli in the biomedical field are temperature, water, and magnetic fields. Using bioprinting materials that can be adjusted according to external stimuli, 4D printing can create an engineered tissue structure that is "active" and has a more complex structure, which is very similar to the natural tissue structure. While inheriting the advantages of 3D printing technology, 4D printing technology has made up for some of the shortcomings of existing 3D printing. For example, 4D printed blood vessel lumen coated endothelial cell membrane can reduce thrombosis and prevent blood vessel blockage; 4D printed drug delivery system can change the drug packaging and release process according to the pH value and temperature change of the internal environment; 4D printed smart response to water coagulation The glue can dynamically reconfigure the structure according to the responsiveness and has no effect on cell viability. In the future, 4D printing technology will have broader applications in the medical field to solve problems in the fields of tissue engineering and drug delivery.

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References

[1] Ren, J., Xu, D., Xu, J. (2020). RANS Simulation for the Maneuvering and Control of a Suboff Submarine Model. FDMP-Fluid Dynamics & Materials Processing, 16(3), 561–572.

[2] Ren, J., Tian, B., Xu, J. (2020). Simulation and Control of Interferometric Synthetic Aperture Sonar Towing System’s Motion Behavior. Basic & Clinical Pharmacology & Toxicology. 20(6), 247-259.

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[3] Ren, J., Xu, J. (2020) Statistical Analysis of Principal Dimensions of Dry Bulk Carriers Navigating on Yangtze River Based on Big Data. Transactions on Edutainment XVI. Lecture Notes in Computer Science, vol 11782.

[4] Ren ,J., Xu, J. Zhou, H.(2019) Estimation of hydrodynamic coefficients of submarine with varying middle body length. UPB Scientific Bulletin, Series D: Mechanical Engineering.12(4),51-67.

[5] Ren, J., Xu, J. (2019) .Research on improved flower pollination algorithm for multi-objective green flexible job shop scheduling. Applied Science Issue.25(5),145-168.