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Optimization Analysis of 3D Printers for High Quality Requirements of Compensation Films

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Abstract: 3D printing technology has the characteristics of rapid prototyping and personalized manufacturing due to its simple operation and efficient molding. It can be used as an important way to manufacture tissue compensation materials for radiotherapy. Compared with traditional processes, it is environmentally friendly and efficient. In addition, it can realize the production of personalized tissue compensation materials. At present, a variety of medical products of tissue compensation materials for radiotherapy manufactured by 3D printing technology have been approved for marketing, but there are still many needs that 3D printers cannot meet. This paper makes a detailed analysis of the current application of 3D printing technology in the field of medical devices for tissue compensation films for radiotherapy, points out the current development dilemma of 3D printed tissue compensation membranes, and discusses the optimization technology of 3D printers according to the specific needs of tissue compensation membranes , which is conducive to promoting the benign development of 3D printing technology in the direction of medical devices.

Keywords: 3D printing; medical devices; technology optimization.

1. Introduction

In recent years, with the rapid development of medical devices and the continuous improvement of the industrial chain, people's living standards have continued to improve, and the requirements for the quality and performance of medical devices have continued to increase. High quality and low price are the future development direction of medical devices, which promotes the continuous updating of medical device production technology. 3D printing technology, also known as "additive manufacturing technology", can greatly simplify the processing technology and save production costs during the production process. Its fast and simple molding method and easy to achieve diversified design characteristics make 3D printing technology a favorite of medical devices such as tissue compensation films for tumor treatment. The use of 3D printing technology to manufacture tissue compensation films for tumor treatment can accurately control the internal gap of the product filaments, enhance the composite force between layers, improve the mechanical properties of polymer composite materials, and arbitrarily control the air permeability of film-type medical devices, solving the difficulty that traditional manufacturing processes cannot achieve the coexistence of skin-friendly, breathable, ultra-thin and high mechanical properties [1] .

At present, the widespread application of 3D printing manufacturing of tissue compensation film medical devices for radiotherapy shows that 3D printed tissue compensation membranes have good clinical efficacy, mainly manifested in: (1) personalized customized products, which can customize the design of tissue compensation membranes according to the differences in each person's face or body shape, greatly improving the customization needs of diversified products [2] ; (2) product microstructure refinement. By printing complex model tissue compensation membranes with 3D technology, the properties of self-healing materials can be used to repair the internal gaps between product filaments, enhance interlayer adhesion, and improve the mechanical properties of the product; (3) ultra-high product production efficiency. For polymer medical device materials with complex structures and personalized structures, they can be decomposed to simplify their structure, and the support link fixing structure can be effectively reduced, so that the production cycle is shortened, and the material utilization efficiency and production efficiency are greatly improved [3] .

2. 3D Printing Technology

2.1. Development of 3D printing technology

3D printing technology was first proposed in the United States in 1980. In 1983, Chuck Hull developed stereolithography technology, laying the foundation for 3D printing technology, and two years later developed the world's first 3D printer. In 1988, Scott Crump proposed the Selective Laser Sintering (FDM) technology, which greatly promoted the rapid development of 3D printing technology. In 2010, Stratasys used FDM to 3D printing technology printed the first car, and 3D printing technology has gradually been promoted in the fields of medical, aerospace, integrated circuits, etc

2.2. Classification and characteristics of 3D printing technology

Since the development of 3D printing technology, more than a dozen printing technologies have been formed, mainly represented by three categories: photocuring technology, laser sintering technology, and fused deposition technology. Among them, photocuring technology is the earliest developed 3D printing technology. Among them, the printing technology represented by stereolithography (SLA) is to polymerize the light and solidify the liquid printing material by light, which has the advantages of high precision and fast molding speed. The laser sintering technology represented by the selected laser sintering technology (SLS) is to melt the powder particles through the extremely high heat source of the laser, spray them to a fixed position and solidify them, and finally re-solidify them into a three-dimensional structure object. Due to the particularity of the solidified material, the objects 3D printed by laser sintering technology do not require other supporting materials, which can maintain the strong support force of the three-dimensional object and effectively ensure the integrity of the molded object. The fused deposition technology represented by fused deposition modeling (FDM) is a 3D printing technology combined with a computer system. First, the object to be printed is three-dimensionally modeled by a computer, and the specific parameters are set by slicing software. The automatically generated program is input into the control end of the printer for intelligent 3D printing. The fused lamination printing technology gradually forms three-dimensional printed products through layer-by-layer printing, which has the advantages of low printing cost, strong personalized printing structure and environmental protection. It has a wide range of applications in medical devices and other fields.

3. Tissue Compensation for Radiotherapy

In tumor radiotherapy, for superficial tumors, whether it is traditional electron beam or X-ray irradiation technology, when electron beam and photon beam enter the human body, due to the dose building effect, the irradiation dose of the superficial target area is extremely uneven, and low-dose areas appear in some superficial areas, thus affecting the effect of radiotherapy. In order to increase the irradiation dose of the superficial treatment target area and reduce the total irradiation dose received by the patient, when formulating radiotherapy plans for shallow tumors, clinicians select tissue compensators of appropriate thickness and density to completely and seamlessly cover the surface of superficial tissues, thereby adjusting the radiation dose distribution and increasing the skin and subcutaneous doses, effectively improving the uniformity of the dose distribution of the superficial target area, and providing radiation physicists with better control of the irradiation dose to the organs at risk (OAR) and the target area when making radiotherapy plans, which can improve the effectiveness of radiotherapy.

3.1. Application of 3D printed tissue compensators

In 2020, West China Hospital of Sichuan University applied 3D printing compensation film technology to nasal NK/T tumor radiotherapy for the first time in the southwest region. West China University used thermoplastic compensation glue (Q Q glue) for 3D printing for radiotherapy of nasal tumors [4] , solving the problem that conventional tissue compensation materials cannot be completely adhered to the skin surface in the treatment of nasal NK/T tumors. Wang Jiaocheng of the People's Hospital of Northern Guangdong used 3D printed compensation film for adjuvant chemotherapy after surgery for breast cancer patients, which can effectively improve the control rate of breast cancer after surgery and reduce complications [5] . Hunan Cancer Hospital used 3D printing technology to develop a tissue compensation material suitable for adjuvant use after radiotherapy of anal canal cancer. The tissue compensation material was closely attached to the patient's skin, and then the film dose was verified using a simulated human model . Finally, it was believed that the 3D printed personalized tissue compensation material met the requirements of prone radiotherapy for anal canal cancer, had a small air gap, and had good adhesion to the patient's skin, which could truly increase the tissue dose of superficial tumors of anal canal cancer [6]

3.2. Dilemmas of 3D Printing in Tissue Compensation

In recent years, 3D printing technology has made many breakthroughs, such as implant polishing technology, shortening printing time, integrating multiple material inlets and outlets into a single nozzle, and printing coating design. However, there are still some difficulties in 3D printing compensation glue that have not been resolved. For example, it is necessary to select new materials with suitable biocompatibility and mechanical properties to achieve radiotherapy auxiliary use in various parts. Tissue compensation glue usually has complex microstructures and small size requirements. In order to meet these requirements and achieve better treatment effects, 3D printing needs to improve printing resolution to achieve printing of smaller size structures and more delicate details. At present, various tissue compensation glue materials have been gradually developed. Some tissue compensation glue materials are quite sensitive to changes in temperature and humidity. Therefore, it is necessary to strengthen the temperature and humidity control capabilities of 3D printers to ensure that the quality and performance of materials are guaranteed during the printing process. Finally, 3D printing technology requires higher automation and intelligence to achieve more accurate and efficient printing.

4. Optimization Methods for 3D Printing

4.1. Optimization of 3D printing materials

Among the tissue compensation materials that have been developed, the most common 3D printing tissue compensation membrane materials are silicone and polystyrene. The density of silicone tissue compensation glue is slightly higher than that of water. It is often cut into any shape when used. It is often used for breast cancer chest wall radiotherapy tissue compensation and is one of the most widely used tissue compensation methods. The performance of polystyrene tissue compensation glue is the same as that of silicone, but the density is lower. At present, new materials suitable for 3D printing are constantly being developed. Thermoplastic polyurethane (TPU) is a high molecular polymer with high deformation rate, strong toughness, low wear and strong flexibility. However, the molecular structure of polyurethane includes hard segments and soft segments. Due to their different polarities, microphase separation occurs. In the application process of tissue compensation membrane, it is necessary to study the flexibility and rigidity of TPU to make it suitable as a raw material for 3D printing tissue compensation membrane. Hydrogel materials have a wide range of applications in the medical field. Yan Yufei [7] used silk protein and polypeptide self-assembly molecules (NapFFRGD) to self-assemble to form hydrogel materials, which have extremely high biocompatibility. Their 3D printing technology has a good therapeutic effect in orthopedic treatment. However, the technology for preparing 3D tissue compensation membranes using hydrosols as materials has yet to be developed.

4.2. 3D Printer Motion Optimization

At present, the 3D printing technology used in 3D printing tissue compensation glue is mostly fused deposition type technology. Since FDM printers are often in a reciprocating motion state with low load, high speed and frequent switching direction, it is very easy to cause the motor to lose steps and generate harmful vibrations, resulting in poor printer molding quality and failure to meet the high-precision requirements of tissue compensation membranes. Therefore, it is necessary to optimize the motion state path of the 3D printer. In terms of suppressing the vibration of the 3D printer, Bian Bingxiao introduced an internal model control algorithm that has low sensitivity to model mismatch and can suppress uncertain influencing factors such as disturbances [8] , and proposed to add an internal model loop that can be equivalent to the superposition effect of external disturbances and input feedforward in the negative feedback channel of the internal model PI control, so as to achieve the optimization of 3D printer motion control under the premise of low cost.

4.3. Optimization of temperature control of 3D printers

At present, when using FDM technology for 3D printing, due to the inaccurate temperature control of the nozzle and the inaccurate start and stop control of the nozzle during the printing process, the printed object surface will be burred and not smooth, which is far from meeting the requirements of tissue compensation membrane. Zhang Yibo [9] changed the traditional PID control method and added a fuzzy PID algorithm to achieve the optimal control of temperature. Based on the FDM molten 3D printing platform, a 57BYG250 stepper motor plus encoder is selected. Through the programming of the PLC controller, the driver outputs a pulse signal, and the driver drives the stepper motor to rotate. An incremental encoder is added to detect the pulse output and feedback to the PLC to adjust the pulse in time, and the motion position is compensated and corrected in real time, forming a stepper motor closed-loop control system, which effectively realizes the optimization and improvement of the nozzle motion temperature control system.

4.4 3D Printer Multi-Nozzle Optimization

3D printing tissue compensation membranes, it is sometimes necessary to use multiple materials for 3D printing. Currently, common 3D printers have only one nozzle. When printing multiple materials, they are printed in a time-sharing alternating working mode, which is inefficient. Su Pengsheng [10] studied FDM 3D printers and designed a dual-nozzle collaborative FDM 3D printer. With the help of specially set slice model data analysis and processing planning, it can realize alternating synchronous printing between two consecutive slices. First, a symmetrical dual-cantilever mechanical structure was designed based on dual-nozzle collaborative printing, and stress analysis and modal analysis were performed on the cantilever structure to ensure the stability of the printer. Secondly, according to the requirements of the dual-nozzle collaborative printer control system, the dual-nozzle collaborative printing path was planned based on the Mega2560 control system, and the temperature control module and motor drive module were modularized The unit circuit design and software system framework diagram were designed based on the control unit. Finally, the printing efficiency can be improved by more than 30%.

5. Conclusion

3D printing technology has great potential and value in the application of medical devices. By using 3D printing technology, medical devices can be designed and produced in a more personalized, precise and cost-effective manner, bringing many innovations and advances to the medical field. According to the special needs of specific medical devices, the optimization and upgrading of 3D printers is the future development direction of 3D printing of medical devices. In the future, medical equipment manufacturers need to increase investment in the technical research and development and application of customized 3D printing technology, actively participate in technical cooperation and transformation at home and abroad, strive for more research funds and professional talent support, and strengthen the construction of internal technical research and development teams.

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References

[1] COUNCIL A, PETCH M, LONG E 3D Printing: Rise of the Third Industrial Revolution[M]. Gyges 3D Presents, 2014.

[2] Zhen Zhen, Wang Jian, Xi Tingfei, et al. Application status of 3D printed titanium orthopedic implants[J]. Chinese Journal of Biomedical Engineering, 2019, 38(2): 240-251.

[3] Zou Quchao, Jin Jinjiang, Huang Tianhai, et al. Research progress of 3D printing technology in the medical field[J]. Chinese Journal of Medical Devices, 2019, 43(4): 279-281, 293.

[4] Li Jin, Huang Yusheng , Yang Zhenzhou and others. Application of 3D printed tissue compensation block in radiotherapy of nasal NK/T cell lymphoma[J]. Chinese Journal of Medical Physics, 2021, 38(11): 1321-1324.

[5] Wang Jiaocheng, Cui Lei, Zhang Qungong and others . The application value of 3D printing technology in adjuvant radiotherapy after breast cancer surgery[J]. Famous doctor, 2022(10): 71-73.

[6] Zeng Biao , Dou Yujiao, Tan Jianfeng and others. Research on 3D printed individualized compensators in radiotherapy of anal canal cancer[J]. China Medical Equipment, 2022, 37(04): 136-139.

[7] Yan Yufei. Construction and efficacy evaluation of biomimetic bone repair biomaterials that induce bone and blood vessel formation[D]. Shanghai: Shanghai Jiaotong University, 2019.

[8] Bian Bingxiao. 3D printer motion optimization method based on internal model control[D]. Xi'an University of Technology, 2022.

[9] Zhang Yibo . Optimization of nozzle motion and temperature control in 3D printing[D]. Taiyuan University of Science and Technology, 2021 .

[10] Su Pengsheng . Design and development of FDM 3D printer based on collaborative printing slicing technology[D]. Xijing University, 2020.