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Investigate the Optimal 3DPrintingParameters for Controlled-Release

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Abstract
This paper used the antihypertensive drugnifedipine as a simulated drug and fused deposition modeling (FDM) 3D printing3D printing techniqueto investigate the optimal printing parameters. It was found that thebest printing outcomeoccurs when the direction of the nozzle extrusion melt is 0°, the printing temperature at 160°C, the printing speed at 20-25mm/s, the printing platform temperature at 25°C, and the layer height at 0.2mm.It is well-known that most of the controlled-release materials are polymer compounds. By mixing with the drug can create desired absorption, distribution, and release of the drug in the human body. Hydroxypropyl methylcellulose (HPMC),a non-toxic material was selected as drug release modifier and hydroxypropyl cellulose as drug-loading material to explore the preparation parameters of filament. HPMC with 10%, 20% and 30% content was used as experimental objects, and the dissolution degree of the printed tablets of different concentrations of hydroxypropyl methylcellulose was investigated.The results showed that the printed tablet with 30% HPMC has the best dissolution effect.A well-dispersed nifedipine in an amorphous state is the key. This experiment demonstrated the feasibility of using FDM 3D printing technology to prepare controlled-release antihypertensive drugs.

Key words: *hydroxypropyl methylcellulose, 3D printing, optimal printing parameters, fused deposition modeling, controlled-release*

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I. Introduction

In recent years, 3D printing technology has developed rapidly and has been gradually applied in all walks of life [1]. With the in-depth study of 3D printing technology, this technology has also made some progress in medical drugs, and the use of 3D printing pharmaceutical preparations has become a research hotspot at this stage, especially in printing tablets, controlled and controlled release preparations and drug transport. Compared with traditional drugs, such as difficulty in swallowing and slow dissolution, most of the finished drugs printed by 3D have porous structures and dissolve quickly, which is conducive to patient consumption and drug absorption. At present, the 3D printing technologies used in the field of preparation mainly include fused deposition modeling (FDM) technology, selective laser sintering (SLS) technology, stereolithography (SLA) technology, and thermal inkjet printing (TIJ) technology [2,3]. Among them, FDM technology is the most widely used in the field of preparation, and commercial FDM printers and printing software are mostly used in the preparation of tablets and slow-release and controlled-release preparations.

The national pharmaceutical industry has always been the embodiment of a country's economic and technological strength.Even though the application of 3D printing technology in Chinese pharmaceutical industry has progressed significantly, there are still many areas worthy of further development and improvements [4]. To further expand the application of 3D printing technology in medical and pharmaceutical applications, this study focuses on exploring the optimal 3D printing conditions and realizing the use of FDM 3D printing technology in printing of a controlled-release tablet with nifedipine as a simulated drug.

3D printing technology& FDM

3D printing (3DP) is a type of rapid prototyping technology, also known as additive manufacturing.It uses adhesive materials such as powdered metal or plastic, and printing objects in a layer-by-layer fashion. In 1983, Charles Hull invented the technology to print digital assets into three-dimensional models [5]. Shortly thereafter, a stereolithography process that uses ultraviolet irradiation to solidify resin into shape to create objects was invented, and 3D printing technology was officially put on the market. Since then, 3D printing

technology has begun to evolve rapidly.For example,FDM technique using thermoplastic materials such as wax, ABS, PC, and nylon to make objects has been born; selective laser sintering technology (SLS) uses a discrete intensity laser to sinter nylon, wax, ABS, metal, ceramic and other material [6,7].With the increase in the variety of 3D printing technologies, the field of 3D printing applications is becoming more and more extensiveand diverse [8]. Today this techniquehas been used in jewelry, footwear, industrial design, architecture, engineering and construction (AEC), automotive, aerospace, dental and medical industries, education, geographic information systems, civil engineering, firearms, and other fields [9].

Since FDM process was successfully developed by American scholar Scott Crump in 1988[10], it showed the advantages of the straightforward construction principle and simple operation of the hot melt extrusion head system. In this study, weused the antihypertensive drugnifedipine as a simulated drug and fused deposition modeling (FDM) 3D printing3D printing techniqueto investigate the optimal printing parameters.

Materials& Instruments

The sample materials used in the FDM printing are shown in the Table 1. The quality grade and its manufacturer also listed. These materials were used without further processing or purification.

Table **1 Drugs required for experiments**

reagent	Specifications	Manufacturer
HPMC	AR	Hubei Huizepu Pharmaceutical Technology Co., Ltd.
HCl	AR	Chongqing Changpeng Chemical Co., Ltd.
Nifedipine	AR	Chongqing Changpeng Chemical Co., Ltd.
PLA	AR	Nature Works

The instruments required for the experiment are shown in Table 2 below:

Table 2 Instruments required for experiments

instrument	Model	Manufacturer
Electronic balances	JJ224BC	Manufacturer: Huazhi (Fujian) Electronic Technology Co., Ltd
FDM	Core XY	Wuhu Senlang Electronic Technology Co., Ltd
Consumables extruder	Wellzoom B	Hongtu Machinery and Equipment in Erqi District, Zhengzhou City
UV/VIS spectrophotometer	I3	Jinan Haineng Instrument Co., Ltd
Blast drying oven	101-1AB	Beijing Zhongxing Weiye Century Company
Dissolution tester	RC-6	Tianjin Optical Instrument Factory

ControlledRelease Materials

Most of the controlled-release materials are polymer compounds, and the addition of controlled-release preparations to the drug can extend the absorption, distribution, metabolism and excretion process of the drug in the human body by appropriate methods, and achieve the purpose of prolonging the efficacy. It meets the requirements of clinical treatment, increases the safety and efficacy of medication, and achieves the purpose of convenient application of preparations, and the second-generation dosage form proposed by extending absorption is the main means adopted by pharmacy. Most drugs in use today are absorbed by a passive diffusion mechanism, and the rate of drug absorption is controlled by the concentration of the drug at the absorption site. If the formulation method is adopted, the excipients that affect the dissolution and diffusion of the drug from the preparation are added in the prescription design, the concentration of the absorption site can be controlled and the absorption can be delayed, and the excipients that can play this role are called slow-release materials, and most of the materials that can play a controlled release role are polymer compounds: adding slow-release materials to the prescription is one of the important means of pharmacy to extend the effect of the preparation. Other methods such as controlling the size of drug particles, making implants, making microsurfaces, coatings, emulsifiers, and making dispersion systems that are incompatible with interstitial fluid, etc., these manufacturing processes and preparation technologies can also achieve the purpose of effect extension.

Under normal circumstances, the main methods of controlled release of material loading drugs include embedding method, solution adsorption method, and direct filling method; Controlled-release material and drug binding is further divided into physical binding and chemical binding. In 3D printing applications, the methods of adding slow-release materials to it for printing are mainly divided into two types: impregnation method and hot melt extrusion method. The impregnation method refers to the solid powder or a molded solid of a certain shape and size (carrier or catalyst containing the body) soaked in a soluble compound solution containing active components (main and co-catalytic components), where the filament -drawn slow-release filament is soaked in the drug solution, and then the residual liquid is separated after contact for a certain period of time. In this way, the active components of the drug can be attached to the solid in the form of ions or compounds. For hot melt extrusion, it refers to a technique in which the drug and the carrier excipient are uniformly mixed in the molten

state and extruded at a certain pressure, speed and shape. The hot melt extrusion method requires a higher temperature, so it is necessary to consider whether the melting point of the raw material meets the requirements when using it.

Compared with the impregnation method, the hot melt extrusion method saves drugs and reduces material waste, and the raw materials selected in this experiment meet the requirements of the hot melt extrusion method. Therefore, the hot melt extrusion method was used to extrude the material in this experiment [11,12].

The controlled-release material selected in this experiment is hydroxypropyl methylcellulose (HPMC), which belongs to one of the nonionic cellulose mixed ethers. It is a semi-synthetic, inactive, viscoelastic polymer that appears as a fibrous or granular powder in the form of white or off-white in appearance. The material is safe and non-toxic, non-irritating to the skin and mucous membranes, in addition, environmentally friendly, just pay attention to avoid random throwing caused by a large amount of dust. Moreover, hydroxypropyl methylcellulose is often used as a rate-controlled polymer material for controlled-release preparations in the pharmaceutical industry, and the selection of it as a slow-release material has a good slow-release effect. The drug-loaded material selected in this experiment is hydroxypropyl cellulose, which is a semi-synthetic organic compound. Its appearance is a white or off-white powder, difficult to dissolve in benzene and ether at room temperature, soluble in water, methanol, ethanol, isopropanol and other polar organic solvents. In addition, the material itself has no pharmacological effect, is non-toxic and is physiologically harmless.

Preparation and Results

1. Determine optimal extrusion temperature

It is known that the melting point of hydroxypropyl methylcellulose HPMC is 225-230 °C, the melting point of hydroxypropyl cellulose HPC is 155-185 °C, and the melting point of nifedipine is 171-175 °C. The temperature of the blast drying oven was set at 40 °C, and the drug used in the experiment - nifedipine, etc. was dried for 24 hours. The moisture absorbed by the surface of the experimental raw material is reduced by drying, which prevents pores on the sample surface and causes experimental errors in the subsequent operation of melt blended drugs. After the experimental raw materials are fully mixed, they are put into the hot melt extruder for filament drawing, and different temperature gradients are set to judge the extrusion temperature with the best melting effect.Set to 150°C, step by step, add the mixed raw materials to the extruder, observe the molding of the extruded material, and continuously adjust the extrusion speed and traction speed of the extruder, and finally obtain the optimal extrusion temperature. On this basis, qualified filaments are obtained and sorted and collected as backup.

2. Determine the optimal printing parameters

Using the modeling software Repetier-Host to open the model file, the tablet set in this experiment is a conventional oval cylinder, with a layer height of 0.2mm. Adjust the printing parameters such as printing temperature, printing speed, platform temperature, etc., adjust them one by one using the control variable method, 3D printing under different parameters, and observe the printing situation to explore the best printing parameters.

According to the consistency of the model slice printed by the FDM printer and the integrity of the obtained sample, observe whether the discharge material can be smoothly adhered to the platform, whether the printing process is continuous and uninterrupted, and whether the model can be printed completely, and analyze and study from these aspects [13]. If there is an error in the middle of printing, the computer displays an error, you should stop printing in time and readjust the temperature or height of the printing platform to make the printing proceed smoothly. After the sample to be printed has cooled, it is measured with a vernier caliper to ensure that the product meets the expected effect, and the best parameters are selected according to the printing situation of different parameters.

3. Extruding the quality filament

The required raw materials are weighed with an electronic balance, and the total mass of the materials is set at 40.00g. After obtaining the optimal extrusion temperature, the mass of nifedipine is positioned at 50%, that is, 20g, and the rest of the raw materials such as hydroxypropyl cellulose are configured with different percentages. The filament formula ratio is shown in Table 3 below:

Table 3 Three different filament formulations

No.	HPC%(w/W)	Nifedipine %(w/W)	HPMC%(w/W)
1	40	50	10
2	30	50	20
3	20	50	30

Accurately weigh each raw material according to the proportion, put it in a beaker and seal it, and dry it thoroughly. Pour the mixed raw materials into the hot melt extruder in batches, start the extruder and set the temperature to 150°C, and wait for the temperature to rise. When the temperature reaches 150 °C, open the extrusion switch, draw and cool the raw materials after extrusion, and turn off the extruder after the preparation of the three kinds of filament , and the filament is classified and rewind.

4. Characterization and quality assurance

In this experiment, calculated dissolution and infrared detection will be used to detect and characterize the dissolution behavior of the target drug.Solutions with different pH values were configured as the dissolution, Fourier transform infrared (FT-IR) spectroscopy is used to determine the concentration of the printed 3D sample over the time. Three tests were carried out for each drug. The dissolution time was initially set for 12 hours, and data was recorded every half hour for the first two hours, and every two hours thereafter. The absorbance of the printed simulated drug, i.e., nifedipine controlled-release tablets, was measured using a UV/VIS spectrophotometer, and the dissolution was calculated.

5. design of 3DP Experiments

The fully mixed formula (Table 3)can be poured into the hot melt extruder in batches for extrusion. The thickness of the printed drug in the shape of a conventional tabletis to be set to 0.20 mm. It is necessary to optimize the temperature of extrusion and of the printing platform during the filament extrusion and adjust as necessary. Total ten (10)trials of extrusion parameters are shown in Table 4.

Table 4 The extrusion parameters settings

No.	extrusion temperature	extrusion speed	No.	extrusion temperature	extrusion speed
1	150	10/20	6	160	20/25
2	150	20/25	7	165	10/20
3	155	10/20	8	165	20/25
4	155	20/25	9	170	10/20
5	160	10/20	10	170	20/25

6. Dissolution test and controlled release

The samples printed with different formula were tested under acidic and neutral conditions using a dissolution tester.ThepH=1 acidic solution was prepared as follows: 8.33mL of 12mol/L hydrochloric acid solution was addedinto 10.00 L of deionized water. During the dissolution test, Cn mL of sample was taken out to for FT-IR measurement. Equation 1below calculates the cumulative percentage of drug release at each time intervalW(%).

$$W = \frac{C_n \cdot \left[V_2 - (n-1) \cdot V_1\right] + \left(C_{n-1} + \cdots + C_1\right) \cdot V_t}{L} \times 100\% \qquad (2\text{-}1)$$

where n represents the nth sampling, Cn is the concentration of the nth sampling, Vt is the volume of dissolution (5mL) sampled at time t, and L is the theoretical drug content [15].

II. Discussions

1.Preparation of drug-loaded filaments

Two printing materials hydroxypropyl cellulose (HPC)and hydroxypropyl methylcellulose (HPMC) were mixedat different proportions with the compatibilizer nifedipine. The mixturewill then put into the extruder to prepare filament. Because the melting point of HPC is about 170 °C, the melting point of HPMC is about 230 °C. Therefore, if the temperature of the mixed filament is lower than 190 °C during extrusion, HPCis not melted and will block the outlet; If the temperature is higher than 230°C, HPC will expand during extrusion, resulting in uneven filament diameter.This will cause extrusion speed uncontrollable, affecting the printing quality.When the ratio of HPC is more than 50% of the mixture, the material will completely melt into liquid phase and the extrusion will fail. The ideal amount of HPC is set at 40%. Therefore, it is necessary to observe the extrusion outlet of the material often during extrusion and adjust necessary to prevent filament deformation. The good quality of printed filament is shown in Figure 1.

Fig.1 the printed filament

2. Influence of extrusion temperature

The drug is thoroughly mixed and put into the feed port of the single screw extruder. Because the melting point of hydroxypropyl cellulose is about 170 ℃ and the melting point of nifedipine is about 230 ℃, the extrusion temperature of drugs with hydroxypropyl cellulose content of 50% and above is preheated to above 150 ℃ during extrusion, and the extrusion temperature of drugs with nifedipine content of 50% and above is preheated to between 170 ℃ - 230 ℃. The investigation of the extrusion temperature is shown in Table 5. Based on theextrusion output and formation results, one can see that theoptimal drawing temperature is in the range of 156-158℃.

Table 5. Investigation of filament drawing temperature

T/℃	Melted state	extrusion	forming
150-152	unmelt	F	F
153-155	slightly soluble	T	F
156-158	melted	T	T
159-161	melted	T	T
165-170	Over-melting	T	F

3. optimal printing parameters

3D printing path refers to the path of nozzle movement during printing. It is known that the choice of 3D printing path will affect the final tablet molding effect, and the following lists 3 different 3D printing paths, as shown in Figure 2.

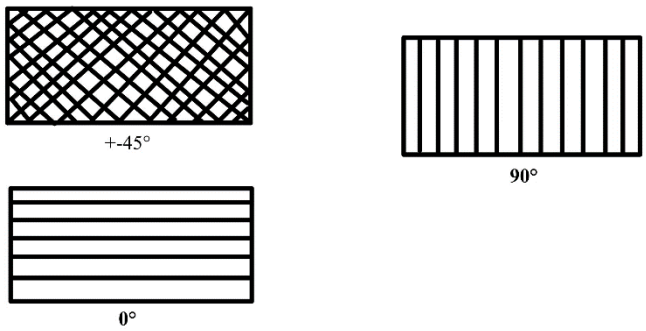

Figure 2. Three printing paths to be tested.

Test each path based on the path selection shown in the preceding figure. Fixed printing temperature, speed and other printing parameters, controlled variables, printed each path, and tested the mechanical properties of the products printed by each path. From the four aspects of tensile strength, bending strength, tensile elastic modulus and flexural elastic modulus, the test results are shown in Figure 3.

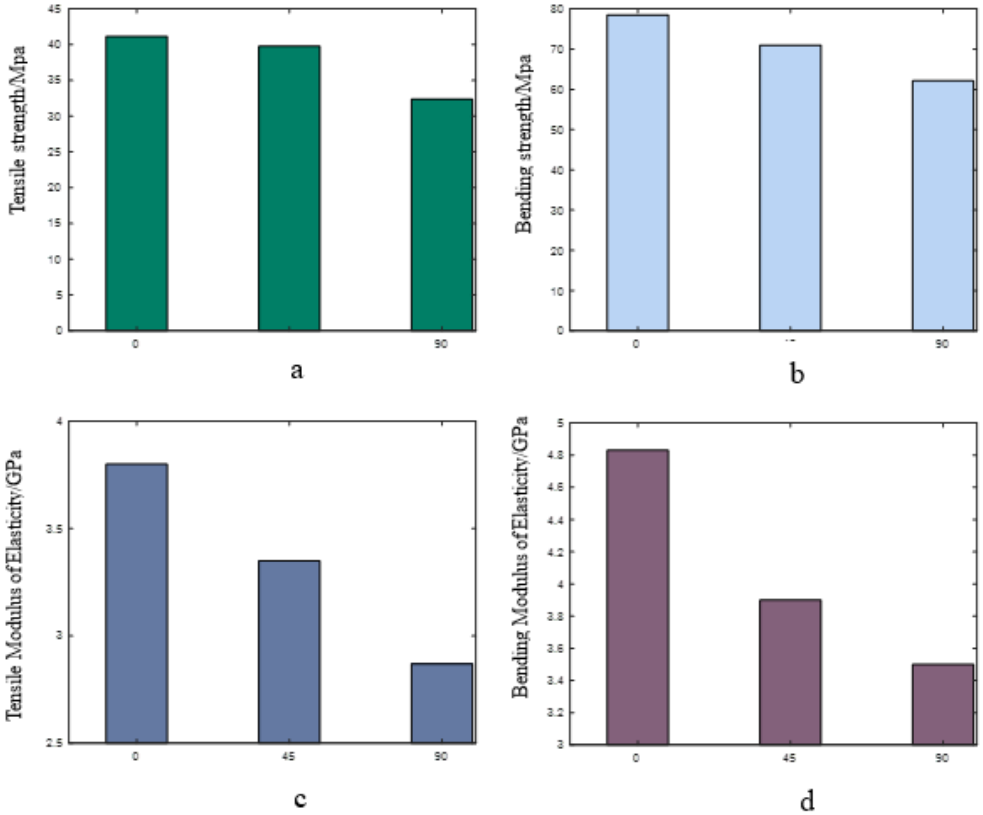

Figure 3. Schematic diagram of mechanical test results

As can be seen from Figure 3-2 above, the four aspects of the test are gradually decreasing for 0°, ±45°, and 90°. When the 3D printing path is 0°, the tensile strength and bending strength are 41MPa and 79MPa, respectively, while the tensile strength and flexural strength at 90° are significantly reduced, which are 27% and 26% lower than 0°, respectively. The intensity of 90° is 32MPa and 62MPa, respectively. According to the measured data, it can be known that when the path is 0°, the resulting printed products are more tightly bonded, making the mechanical properties of the material under the path more powerful. Therefore, 3D printing chooses 0°.

According to the predetermined printing parameters in the experimental protocol, controlvariables, the printing speed is set to 20/25mm/s, and the test is carried out at the printing temperature of 150°C, 155°C, 160°C, 165°C, 170°C, and the experimental results are shown in Table 5. One can see the best printing temperature would be 160°C

Table 5 Tablets at different printing temperatures

T/℃	150	155	160	165	170
Sample surface	rough	Smoother	smooth	smooth	rough
Interlayer fit	x	x	√	√	√
appearance	x	∧	√	∧	x

4. The dissolution tests

To understand the effect of controlled-release of these printed materials, the dissolution test of samples was performedby detecting the amount of simulated drug nifedipine dissolvedin the solution. Be noted that the dissolution effect is based on the mass fraction of 50%nifedipine. Since the drug is released in the human stomach environment with strong acid, the simulated controlled release will be performed in a hydrochloric acid solution with pH = 1.There are three samples to be tested: Sample #1 (50% nifedipine, 40% HPC, 10% HPMC), Sample #2 (50% nifedipine, 30% HPC, 20% HPMC), Sample #3 (50% nifedipine, 20% HPC, 30% HPMC).Three parallel experiments were carried out on each sample with a dissolution time of 12 hours. Ultraviolet-visible spectrophotometer was used to record the absorbance and calculate according to Equation 1 to obtain dissolution percentile.

Figure 4ashows the dissolution curve of sample #1. Three trials (triangle and diamond) and their average fitting (purple line) are shown in the Figure.One can see that the dissolution of the three trials of sample

#1 are roughly the same.The deviation amongtrials at 300-400 minutes suggest that the release rate of trials 1 and 2 is similar.The dissolution of sample #1 increases over the time, and almost plateaued at 11thhour. When the HPMC content increased to 20% of sample #2 and 30% of sample #3, the dissolution of sample 2 and sample 3 also increases over the time. However, Figure 4b & 4c shows samples #2 and #3plateaued at 8 hours and 5 hours, respectively. Furthermore, the dissolution of both samples #2 and #3 would reach 80% more while that of sample #1 only reaches 30% by the end of 12-hour3period.

As a comparison, a neutral solution with a pH of 7 was used to investigate the dissolution of sample #3.Figure 4d showed the dissolution continues over the time as usual. However, sample #3 in neutral solution would reach the plateau by 4th hour. This shortest time to reach 90% dissolution. This suggests that 30% HPMC content is more suitable in the early stage under neutral conditions. Also, higher the HPMC content, the shorter the dissolution time.

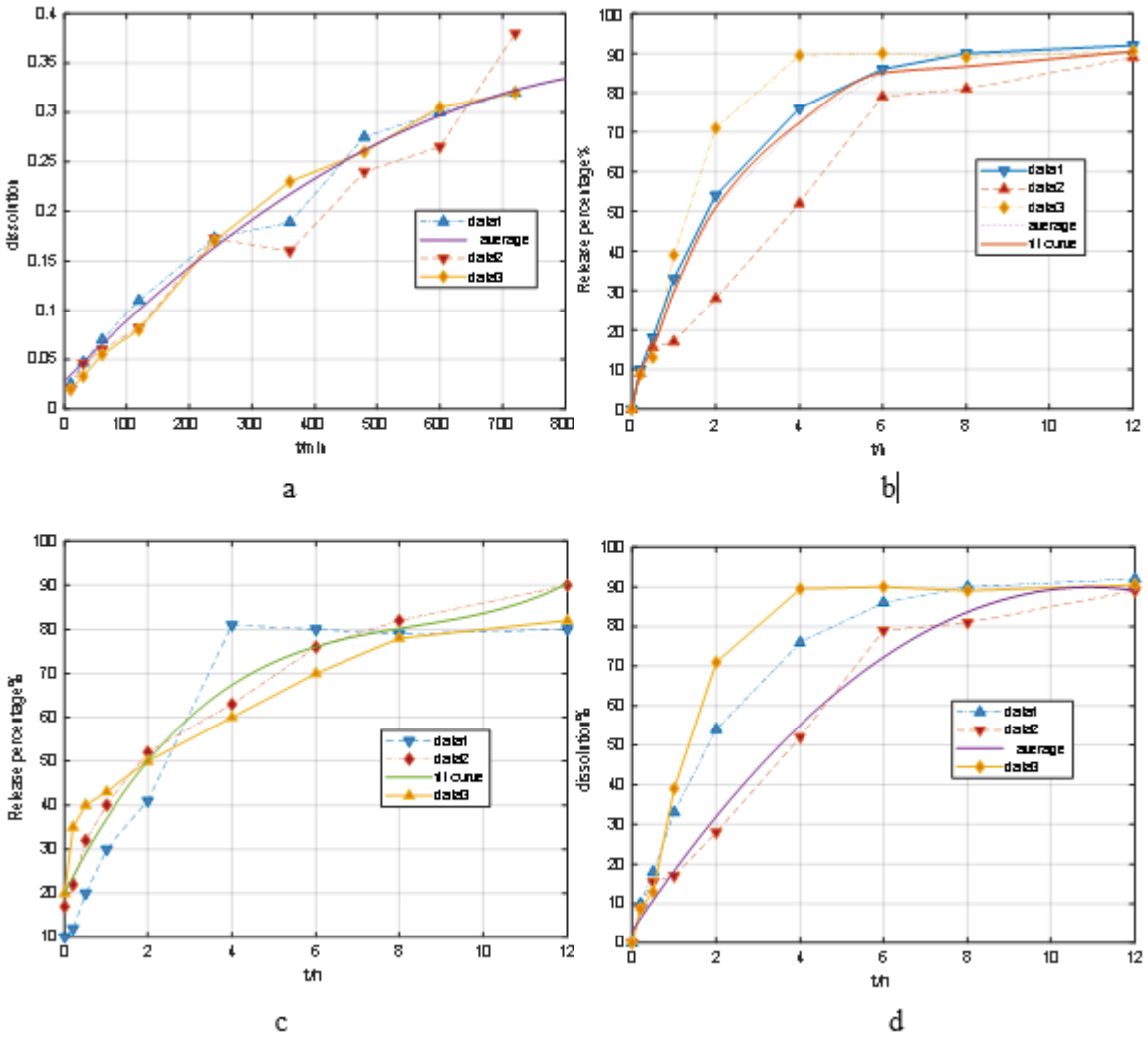

Figure 4. the dissolution curve in pH=1 solutionof Samples #1 (a), #2 (b), #3 (c), and #3 in pH=7 solution (d).

III. Conclusions

The study investigated hydroxypropyl cellulose (HPC) as a drug-loading materialin 3D printing. Hydroxypropyl methylcellulose (HPMC) is used ascontrolled release agent, and uses antihypertensive drug - nifedipine as a simulated drug to monitor the dissolution release. In this experiment, the optimal printing path, printing temperature and printing speed were explored, and the optimal printing parameters were selected for infrared characterization and detection, which expanded the research of 3D printing in biomedicine such as controlled release. The conclusions reached are as follows:

1) Under the same printing parameters such as printing temperature and speed, the better printing quality when the printing path is set to 0° such as the structure of the drug will be tighter, and the surface will be smoother.

2) The extrusion temperature of HPC as a drug-loaded material increases with the increase of hydroxypropyl cellulose content, and with the increase of hydroxypropyl cellulose content, the extrusion temperature of the material increases by about 10 °C.
3) Through the optimization of printing parameters such as printing temperature, printing path, printing speed, etc., the best printing parameters are the printing temperature is 160 °C, the printing speed is 20/25mm/s, the printing platform temperature is 25 °C, and the layer height is 0.2mm.
4) The dissolution rate of neutral conditions and acidic conditions were both investigated.The dissolution amount of the drug is lower when HPC contain is high (sample #1 with 30% HPC). When increase the HPMC content, the dissolution reaches plateau curve becomes shorter. is, 50%

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Reference

[1]. 61. Ben Yao, Zhining Xu, Jianan Liu, Liang Yang, Jianping Shang, Jingyuan Fan, Lizhi Ouyang, Hua-Jun Shawn Fan，Design a viable 3DP processing for producing effective controlled-release pesticide, American Journal of Science, Engineering and Technology, 8(1), March 2023, 32-40, 10.11648/j.ajset.20230801.14
[2]. CUI Fengbo, Zhang Ping, Ran Wenhua, SHEN Linfeng, CUI Lirong. Evaluation of 3D printed glass fiber reinforced hydroxypropyl cellulose [J]. Engineering Plastics Application,2023,51(02):29-33.
[3]. Mi L, Bai Na. Research progress of 3D printing polyether ether ketone and composite materials in stomatology [J]. Journal of Jinan University (Natural Science & Medicine),202,43(06):616-622+642.
[4]. Sang Yanan, Gao Jie, Miao Pengpai, Han Xiaobing, Chen Tao. Research progress of drug controlled-release materials [J]. Fine & Specialty Chemicals,2022,30(11):4-13.DOI:10.19482/j.cn11-3237.2022.11.02.
[5]. Chuck Hull, patentUS6027324A "Apparatus for production of three-dimensional objects by stereolithography", August 8, 1984
[6]. Yan Cunfu, Qiao Xuetao, Guo Xiaohong, Cha Baoxiu. Process parameter optimization of 3D printing warping deformation based on melt deposition [J]. Engineering Plastics Application,2021,49(12):77-80.
[7]. SONG X H. Study on properties and melting deposition of hydroxypropyl cellulose/shell powder composite [D]. Guangxi university, 2021. DOI: 10.27034 /, dc nki. Ggxiu. 2021.000043.
[8]. Chen H Y. Research on temperature control and precision improvement of the forming chamber of molten deposition additive manufacturing [D]. Hangzhou university of electronic science and technology, 2021. DOI: 10.27075 /, dc nki. GHZDC. 2021.000047.
[9]. Shi Yuntao. The application of 3 d printing in medicine [J]. Journal of modern information technology, 2019, 3 (19) : 177-178. The DOI: 10.19850 / j.carolcarrollnki. 2096-4706.2019.19.063.
[10]. Yao Qing, Tang Xing. Hot melt extrusion technique was used to prepare nifedipine solid dispersions of study [J]. Chinese journal of pharmacy (online), 2014, 12 (6) : 177-184. The DOI: 10.14146 / j.carolcarrollnki CJP. 2014.06.001.
[11]. Gao Xianfeng, Gao Jianqing. Hot melt extrusion technique was used to prepare nifedipine solid dispersions [J]. Journal of modern applied pharmacy in China, 2012, 29 (11) : 1002-1006. The DOI: 10.13748 / j.carolcarrollnki issn1007-7693.2012.11.024.
[12]. ZHAO H L, WANG C, GAO J D, et al. Research progress of 3D-printed pharmaceutical excipients [J]. Journal of Clinical Medicine Literature Electronic, 2019, 6(03):200-201.
[13]. Chen Guoning, Shu Hua, YU Pei, Luo Zhimin, Du Wei, Chang Chun, Fu Qiang. Application of 3D printing technology in pharmaceutical research [J]. Chinese Journal of Pharmacy (16):1353-1359.
[14]. Shao Sai, Wu Jing, Zhao Caifeng, Zhang Leping, Xie Hongke, Guo Feng, Li Hongguang, Zhou Yiji, Zhang Yuelong, Hu Die, Tu Xiaoyi, Qi Hui. Preparation and properties of starch based pesticide slow-release materials by radiation [J]. Chinese Journal of Laser Biology,202,31(05):427-432. (in Chinese)
[15]. Qin Lei, LIU Weifeng, Liu Xuguang.3D printing and chemical engineering: Symbiotic development and risk control [J/OL]. Journal of Taiyuan University of Technology :1-13[2023-03-10].