Research progress in 3D-printed medicinal tablets

Naijun Dong*, Hongqian Lv*, Cheng Liu* and Peng Zhang* *

*Correspondence: zhangpengspu@163.com (P. Zhang)
Tel. and Fax: +86-24-23986256

Received: 25 December 2021; Revised: 28 February 2022; Accepted: 22 March 2022
Published online: 14 April 2022
DOI 10.15212/AMM-2021-0010

ABSTRACT

Three-dimensional printing (3DP) is a rapid-prototyping technology that uses a digital model file to construct an object through layer printing. This novel technology is widely used in aerospace, medicine, architecture and industrial applications. However, the pharmaceutical applications of 3DP technology remain in early stages, and the pharmaceutical industry is expected to experience a revolution in 3DP. Herein, recent research progress in 3D-printed medicinal tablets is reviewed, to provide a reference for future studies and applications of 3DP technology in pharmaceutics.

Keywords: 3D-printed tablets, 3D printing, pharmacy, fused deposition modeling, hot melt extrusion

1. INTRODUCTION

Three-dimensional printing (3DP) technology originated in the United States at the end of the 19th century and was advanced by the development of computer and network technology in the 1980s. In 1986, Charles Hull [1], an American scientist, developed the first commercial 3DP press. In 1993, at the Massachusetts Institute of Technology, Sachs and Cima obtained 3D entity printing patents, which provided a foundation for the rapid development of 3DP technology. This technology is a new type of digital forming technology, enabling rapid manufacturing of 3D objects with complex customizable shapes through the precise 3D stacking of materials under the control of a computer, according to a computer-aided design model or computed tomography [2,3]. Various 3DP technologies have been widely used in many fields, such as aerospace technology, automobile manufacturing, architectural design, manufacturing and biomedical materials, but its application and development in the pharmaceutical field have lagged behind [4]. Multiple 3DP techniques are used, such as fused deposition modeling (FDM), semi-solid extrusion (SSE), stereolithography apparatus (SLA), selective laser sintering (SLS), digital light processing (DLP) and binder jetting [5]. The materials used for pharmaceutical printing are summarized in Table 1, and applications of 3D-printed medicinal tablets are summarized in Table 2. In 2015, after the U.S. Food and Drug Administration approved the first levetiracetam instant tablets prepared with 3DP technology, research enthusiasm regarding 3DP drugs greatly increased worldwide [6].

At present, 3DP technology cannot compete with the traditional solid-dosage-form manufacturing process. Although 3DP is slower than traditional mass production, pharmaceutical companies can take advantage of this method in applications in which mass production is not required. For rare diseases, although the patients are few and the demand for drugs is low, the cost is prohibitively high. If drugs are produced in large quantities, problems pertaining to drug storage, validity and price result. However, 3DP technology’s low costs for individualized and small-batch production may be advantageous in such scenarios. The emergence of 3DP technology has helped usher in the personalized medical era [7–9]. Because of interindividual differences, people given the same dose of drugs show significant differences in drug reactions [10]. Drug personalization can decrease adverse reactions in such cases. Whereas traditional drugs are produced in single shapes, 3DP can print different shapes [6], thus enabling the production of various oral dosage forms and medical devices [11,12]. Khaled et al. have shown that 3D extrusion can be used for printing high-dose paracetamol tablets, a process not possible through conventional manufacturing methods, because of limitations in material blending and tableting compression. In addition, for children with difficulties in taking medications, customized
tablet shapes could be printed to improve patient compliance [13]. Because the dosages of drugs taken by children vary among individuals, 3DP may be valuable in facilitating personalized administration [14, 15]. Because 3D-printed tablets have abundant pores and an extremely high internal surface area, they can quickly dissolve in small amounts of water. This feature is beneficial for some patients with dysphagia. Together, these advantages highlight the excellent prospects and potential of 3DP technology in the pharmaceutical field.

In 3DP for pharmaceutics, a 3D printer is used to manufacture different dosage forms through computer-aided drug-design technology. Complex personalized products can be printed on demand with 3DP. Compared with the traditional pharmaceutical preparation process, 3DP technology has high controllability and flexibility, thus making it suitable for the manufacturing of personalized and innovative preparations [16]. Because of the growing demands for personalized dosages and products with specific drug-release behaviors in clinical settings, 3DP technology in the development and production of various drug delivery systems is expected to be increasingly applied to solve problems in complex drug delivery programs and specific patient populations.

Herein, we reviewed studies on 3D-printed tablets and searched references with titles including “3D printing/3D printed” and “tablet” in Web of Science. In general, 3D-printed tablets follow a common process of printing production (Figure 1) involving the following steps: (i) design, in which computer-aided-design software is used to design a 3D representation of the

**Table 1 | 3DP technologies and materials**

<table>
<thead>
<tr>
<th>3DP technology</th>
<th>Materials</th>
<th>Examples of materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>FDM</td>
<td>Thermoplastic polymer filament</td>
<td>PVA, PLA, HPMC, HPC, TEC, TCP</td>
</tr>
<tr>
<td>SLA</td>
<td>Liquid photopolymer</td>
<td>PEG</td>
</tr>
<tr>
<td>SSE</td>
<td>Thermoplastic polymer filament</td>
<td>HPMC K100LV, PVP K30, Precirol ATOS</td>
</tr>
<tr>
<td>SLS</td>
<td>Thermoplastic polymer filament</td>
<td>PVA/PEG graft copolymer, HPMC, Kollidon® VA 64</td>
</tr>
<tr>
<td>DLP</td>
<td>Liquid photopolymer</td>
<td>PEGDA and PEGDMA</td>
</tr>
<tr>
<td>Binder jetting</td>
<td>Powder</td>
<td>Lactose monohydrate, PVP K30, di-calcium phosphate anhydrate</td>
</tr>
</tbody>
</table>

**Table 2 | Applications of tablets produced using different 3DP technologies**

<table>
<thead>
<tr>
<th>3DP technology</th>
<th>Aim</th>
<th>API</th>
<th>Excipients</th>
<th>Refs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binder jetting</td>
<td>The printability property of the ink solutions</td>
<td>Amitriptyline hydrochloride</td>
<td>Lactose monohydrate, Polyvinyl pyrrolidone K30, and Di-Calcium phosphate Anhydrate</td>
<td>[17]</td>
</tr>
<tr>
<td>UV inkjet</td>
<td>The viability of 3D inkjet printing with UV curing to produce solid dosage forms</td>
<td>Carvedilol</td>
<td>Irgacure 2959, and a photocurable N-vinyl-2-pyrrolidone (NVP) and poly(ethylene glycol) diacylate matrix</td>
<td>[20]</td>
</tr>
<tr>
<td>SSE</td>
<td>Fabrication of controlled release tablets</td>
<td>Melevodopa, Acyclovir</td>
<td>Precirol ATOS</td>
<td>[50]</td>
</tr>
<tr>
<td>FDM</td>
<td>Fabrication of extended release tablets</td>
<td>Prednisolone</td>
<td>PVA</td>
<td>[71]</td>
</tr>
<tr>
<td>FDM</td>
<td>Fabrication of controlled release tablets</td>
<td>Paracetamol</td>
<td>PVA</td>
<td>[72]</td>
</tr>
<tr>
<td>DLP</td>
<td>Fabrication of controlled release tablets</td>
<td>Ciprofloxacin hydrochloride</td>
<td>PVA</td>
<td>[34]</td>
</tr>
<tr>
<td>SSE</td>
<td>Fabrication of controlled release tablets</td>
<td>4-amino salicylic acid (ASA) or 5-ASA</td>
<td>PVA</td>
<td>[33]</td>
</tr>
<tr>
<td>Hot melt inkjet</td>
<td>Fabrication of controlled release tablets</td>
<td>Budesonide</td>
<td>PVA</td>
<td>[73]</td>
</tr>
<tr>
<td>SLA</td>
<td>Fabrication of controlled release tablets</td>
<td>Fenofibrate</td>
<td>Beeswax</td>
<td>[41]</td>
</tr>
<tr>
<td>SLS</td>
<td>Produce small oral dosage forms with modified release properties</td>
<td>Paracetamol, Ibuprofen</td>
<td>EC</td>
<td>[74]</td>
</tr>
<tr>
<td>DLP</td>
<td>Fabrication of modified-release tablets</td>
<td>Theophylline</td>
<td>PEGDA and PEGDMA</td>
<td>[52]</td>
</tr>
</tbody>
</table>
object; (ii) preparation, in which printlets are prepared by selecting the 3DP technology, excipients and printing parameters, which are based on the characteristics of the drugs and desired outcomes; and (iii) distribution, in which the 3D printer is filled with the drug-loaded feedstock.

2. 3D-PRINTED TABLETS

2.1 3D-printing technologies

3DP technologies and materials are presented in Table 1.

2.1.1 Fused deposition modeling. FDM is a method of heating and melting various hot melt filamentous materials (Figure 2). The temperature of the hot melt material is always slightly higher than the curing temperature, whereas the temperature of the formed part is slightly lower than the curing temperature. After the hot melt material is extruded from the nozzle, it is fused with the previous layer. After the deposition of one layer is completed, the worktable is lowered by the thickness by one layer according to a predetermined increment, and then continues melt spray deposition until the entire solid part is completed.

2.1.2 Stereolithography apparatus. SLA is based on the principle of photopolymerization of liquid photosensitive resin. Under the irradiation of ultraviolet light of a certain wavelength ($\lambda = 325$ nm) and intensity ($w = 30$ MW), a liquid material rapidly photopolymerizes, the molecular weight quickly increases, and the material changes from liquid to solid. SLA is currently the most studied method and is also the method with the most mature technology. Generally, the layer thickness is 0.1–0.15 mm, and the precision of formed parts is high.

2.1.3 Semi-solid extrusion. SSE is a processing method to fill the materials in the coexistence state of a liquid phase and solid phase (semi-solid) into the extrusion cylinder. After pressurizing of the extrusion shaft, the blank flows out of the extrusion die and completely solidifies, and a long product with uniform sections is obtained.

2.1.4 Selective laser sintering. Before processing, the working chamber filled with nitrogen must be heated and kept below the melting point of the powder. During forming, the feeding bucket rises, and the powder-spreading roller moves. First, a layer of powder material is deposited on the working platform, and then the laser beam sinters the powder where the solid parts are located in the cross-sectional profile, under the control of the computer, thus melting the powder and forming a solid profile layer. After sintering of the first layer is completed, the height of one cross-section layer is too low, a layer of powder is deposited, the sintering of the next layer occurs, and the printed model is formed.

2.1.5 Digital light processing. DLP technology uses a high-resolution DLP to cure the liquid polymer layer by layer until the final model is completed. DLP molding technology generally uses photosensitive resin as a printing material.

2.1.6 Binder jetting. In binder jetting, adhesive is sprayed onto a powder material, deposition and stacking occur layer by layer, and the formed parts are printed. After removal of excess powder, the part is transferred to a high-temperature furnace for degreasing and sintering.

2.2 Factors influencing 3D-printed tablets

Although 3DP has progressed in the field of pharmacy, it remains in exploratory stages, and no complete system has been developed. Analysis of the factors affecting tablet printing are important research directions. Ink is an important raw material for 3DP, because its performance influences 3DP film. Additives to the ink are used to improve its printability and consequently the quality of the tablets. The active pharmaceutical ingredient (API) is added to the ink, and the printability of the ink...
solution is quantified [17]. Hydroxypropyl methyl cellulose (HPMC) hydrogel is added, and the hydrogel is usually used as the printing ink [18] in a biological 3D printer. The parameters set by 3D printers greatly influence the performance of tablets. A 3D printer prints out tablets according to the computer settings; therefore, tablet performance is greatly altered if these parameters are changed slightly. The printing temperature affects the color and drug content of the tablets, and the filling density changes the dissolution rate [19]. Tablets with different geometric structures have different release profiles [20], and changes in doses consequently affect tablet safety and personalization [21]. In medical fields, 3DP technology is among the fastest-developing technologies. However, low printing efficiency remains a major limitation of this manufacturing technology for new dosage forms. The addition of drug-free filaments in the printing process enables simple modification of the dose and dissolution profile, and the high stability of the crystal material is particularly conducive to the long-term storage of the precursor [22].

2.3 Applications

2.3.1 Anti-inflammatory drugs. Anti-inflammatory drugs are the main drug category of 3D-printed tablets. Viidik et al. have studied indomethacin and theophylline as model drugs. Physical powder mixtures of polycaprolactone, plasticizer and API have been manually blended, extruded with a single-screw extruder and printed by a table-top FDM 3D-printing system. The combination of polycaprolactone and arabic gum provides an interesting novel polymeric carrier system for combination of polycaprolactone and arabic gum provides an interesting novel polymeric carrier system for 3D-printable hot melt extrusion (HME) filaments and tablets [23].

Khaled et al. have used an extrusion-based 3D printer to prepare paracetamol tablets with different geometries (mesh, ring and solid) [24], whose surface area is directly proportional to the drug-release rate. Similarly, Martinez et al. have prepared tablets of paracetamol dispersed in polyethylene glycol (PEG) by SLA 3DP. They have produced many geometric shapes (cube, disc, pyramid, sphere and torus) with a constant surface area or a constant surface area/volume ratio [25]. Goyanes et al. have used HME to generate paracetamol-loaded filaments from three grades of the pharmaceutical excipient hypromellose acetate succinate (HPMCAS) [26]. In addition, they have demonstrated the potential of 3DP in manufacturing tablets with different geometries [27]. Zhang et al., using acetaminophen as a model drug, have combined the melt-deposition model with HME technology for 3DP to promote the manufacturing of additives, to prepare tablets with enhanced sustained-release performance [28].

Öblom et al. have presented novel formulations containing isoniazid for the prevention of latent tuberculosis and have investigated 3DP technology for personalized production of oral solid dosage forms enabling adjustable-dose and drug-release properties [29]. In Tabriz’s study, FDM has been used to design and fabricate a bilayer tablet consisting of isoniazid and rifampicin for the treatment of tuberculosis [30].

Yang et al. have reported that the drug-release rate is affected by tablet patterns in tablets printed by an FDM printer using filaments containing ibuprofen and ethyl cellulose [31]. Chen et al., using ibuprofen as model drug, have reported that an HME/FDM approach with optimized formulation composition may be an attractive option for the development of pharmaceutical tablets and implants when adjustable drug-release patterns are necessary [32]. Goyanes et al. have used FDM 3DP to produce 5-aminosalicylic acid (5-ASA, mesalazine) and 4-aminosalicylic acid (4-ASA) tablets to demonstrate the feasibility of using FDM 3DP to produce modified-release drug-loaded tablets [33].

Drug-loaded filaments with different ciprofloxacin hydrochloride concentrations have been successfully printed by Saviano et al., and the obtained printlets’ dissolution profiles were almost superimposable. This work represents an important step toward future applications of 3D-printing manufacturing processes to obtain personalized galenic formulations [34].

Huanbutta et al. have developed floating controlled-release tablets with a metronidazole core by using 3DP [35]. The floating shell or tablet housing was prepared with polyvinyl alcohol (PVA). The SSE achieved a high drug-loading potential. High-drug-loaded sustained-release gastric floating clarithromycin tablets have been proposed by Chen et al. [36].

2.3.2 Hypoglycemic drugs. Cui et al. have achieved the customized release of glipizide without changing the prescription by adjusting the print parameters, such as the contour value, grid width and print pattern (Figure 3) [37].

Ibrahim et al. have performed 3DP of metformin HCl–loaded PVA tablets by using fused deposition modeling [38].

Khaled et al. have developed a compound preparation for the treatment of hypertension in patients with diabetes [39]. The tablets included an osmotic pump with captopril, and a sustained-release chamber with nifedipine and glipizide. This study has not only demonstrated the feasibility of 3DP technology for the preparation of composite preparations but also provided a new method for composite preparation. 2.3.3 Cardiovascular drugs. Li et al. have developed novel low-density gastric floating tablets of dipyridamole with a lattice internal structure [40].

Koyobula et al. have used natural material (beeswax) as the drug carrier and fenofibrate as the drug [41]. Johannesson et al. have performed SSE printing of emulsion gels with three types of emulsified lipid-based formulations to produce solid lipid tablets incorporating the poorly water-soluble drug fenofibrate [42].
Amlodipine has been used as a model drug, PVA has been used as a polymer, and excipients including sodium starch glycolate and HPMC HME have been used. In a study by Obeid, proper selection of excipients and/or adjustment of the infill patterns and wall thickness have been described to tailor drug release in FDM 3DP [43].

Matijasic has prepared filaments containing dronedarone hydrochloride, a drug used in the treatment of cardiac arrhythmias [44].

Fuenmayor et al. have combined 3DP with injection molding for mass customization of oral tablets [45].

Chen et al. have shown that FDM 3DP technology can be used to prepare floating dosage forms capable of meeting the requirements of drug-release profiles. Propranolol hydrochloride was selected as a model drug, and drug-loaded PVA filaments were produced by HME [46].

Sadia et al. have prepared a flexible dose combination of two antihypertensive drugs in a double-layer tablet by using a double FDM 3D printer [47]. This dynamic drug delivery system maintains the advantages of fixed dose combinations and provides superior flexibility in the drug delivery range, thus providing an optimal clinical solution for hypertension treatment in patient-centered medical services.

2.3.4 Antipsychotics. Figueiredo et al. have developed a method for the preparation and characterization of paroxetine tablets [48]. Bhatt et al. have demonstrated the feasibility of directly using olanzapine-Kollicoat(R) immediate release through the HME process without the addition of any plasticizers or organic solvents; moreover, coupling HME with 3DP technology has allowed for the construction of prototypes of an immediate-release olanzapine tablet [49].

2.3.5 Purine drugs. Tsintavi has partially coated tablets with the glyceride Precirol ATO 5 by using a semi-solid 3D printer to tune the release of two APIs: the hydrophilic methyl-levodopa hydrochloride (melevodopa) and the lipophilic acyclovir [50].

Giri et al. have combined HME and FDM 3DP to produce floating theophylline tablets with gastric retention [51]. Kadry et al. have used polyethylene glycol diacrylate (PEGDA) and poly ethylene glycol dimethacrylate (PEGDMA) as photoreactive polymers and theophylline as a model drug to produce tablets with a DLP printer [52]. Okwuosa et al. have also used theophylline as a model drug and polyvinylpyrrolidone (PVP) as an inhibitor. The advantages of FDM 3DP at low temperatures may expand the drug spectrum of FDM 3DP and enable on-demand production of personalized dosage forms [53]. Pietrzak et al. have proposed an elastic-dose tablet system, which has been found to be suitable for rapid-release tablets and sustained-release theophylline tablets with real drug loading and an easily swallowed tablet design [54].

Figure 3 | Photographs of: (a) a 3D model of a printed tablet, (b) the desktop SSE 3D dual-nozzle printer MAMII, (c) the organic printing platform and (d) the stainless-steel piston. Copyright 2019, Editions de Sante [37].
2.3.6 Anticancer drugs. Shi et al. have innovated 3DP drug methods and used Drop-on-powder 3DP technology to produce oral tablets containing 5-fluorouracil, a model anticancer drug [55]. Bloomquist et al. have described the application of continual liquid interface production to fabricate biocompatible and drug-loaded devices with controlled-release properties, by using liquid resins containing API. The model drugs are docetaxel and dexamethasone-acetate [56].

2.3.7 Antiepileptic drugs. Lamichhane et al. have built a floating slow-release system based on the FDM, and used HPMCAS, PEG 400 and pregabalin as active components [57]. Hong et al. have used binder jet 3DP technology to prepare personalized multicompartmental structures of drug systems and provided a basis for the development of complex preparations [58]. Borujeni et al. have discussed the possibility of combining HME with 3DP technology to design drug-matrix tablets and achieve zero-level release. Carbamazepine was used as the model drug. Through the combination of HME and 3DP technology, zero-order-release tablets were prepared with a ratio ofethyl cellulose to hydroxypropyl cellulose (HPC) of 2:1, which decreased the necessary dose frequency and the adverse drug reactions. Further improvements have been made [59].

2.3.8 Traditional Chinese medicine preparation. On the basis of the characteristics of 3DP technology, customized and personalized products can be easily prepared, in alignment with the traditional Chinese medicine treatment strategy. The concept of traditional Chinese medicine stresses the treatment of both diseases and people. Even for the same disease type, prescriptions, dosage forms and dosages differ according to patients’ medical history, physical characteristics, age, sex, temperament and other factors. The traditional standardized drug model cannot accommodate these different drug-use patterns, thus hindering the provision of drugs by Chinese pharmacists. In the future, with changes in 3DP pharmaceutical methods, doctors may be able to use 3D printers to flexibly prepare the drugs needed by patients according to their conditions in hospital settings, and to flexibly adjust drug shape, color or taste according to patient preferences. Wang et al. have studied the prescription, warpage optimization and factors influencing 3DP Jiuxiang Jianpi Yangwei tablets [60]. Their research has shown that 3DP technology has great potential in the preparation of traditional Chinese medicine, and has provided guidance for producing 3D-printed tablets without warpage.

At present, several successful examples of preparation of traditional Chinese medicine tablets with different release profiles have been reported. Li et al. have prepared solvent-free rapid-release puerarin tablets with PEG 4000 as the carrier, highlighting the advantages of PEG as a soluble polymer with thermal extrusion 3DP, and have provided a suitable system for the rapid release of puerarin [61]. The authors have also developed a new puerarin gastric floating system with a 3D-extrusion-based printing technique, and altered the flexibility of release behavior through the design of the internal structure [62]. The puerarin gastric floating 3D-printed tablets had good gastric retention time and controlled-release performance. Thus, the 3D extrusion-based printing technique appears to be suitable for the production of oral administration systems, because of its flexibility, large floatability and ability to achieve controlled release.

2.3.9 Other forms. New dosage forms of drugs can improve drug efficacy, prolong the time of action, improve the selectivity for specific sites of action, decrease the numbers of tablets that patients must take simultaneously, and improve treatment effectiveness and safety. To address the problem of opiate abuse, Nukala et al. have developed egg-shaped tablets (egglets) by combining HME with FDM 3DP (Figure 4) [63]. This innovation is expected to be a promising tool for the preparation of immediate-release anti-abuse agents for patients. Awad et al. have reported the use of 3DP technology to produce orally disintegrating printlets suitable for patients with visual impairment [64]. The surface of the printlets was designed with braille and moon patterns, thus allowing patients to identify drugs removed from their original packaging. This novel and practical method should aid in decreasing medication errors in patients with visual impairment and improving drug compliance.

Figure 4 | Photograph of 3D-printed egglets. Copyright 2019, American Association of Pharmaceutical Scientists [63].
3. DISCUSSION

Many remaining problems currently restrict the engineering applications of 3DP preparation. The first problem relates to the materials. Although 3D printers are increasingly being designed according to different technical principles, few can be used for large-scale applications, because the printable materials are limited, and the side effects are the gap that restricts the materials in other fields to enter the field of preparation. The second problem relates to price. Cost is always an important consideration in industrialization. The cost increase due to the non-reusable nature of some consumables also affects the industrialization of 3D-printed preparations. Some studies have suggested that people might use 3DP technology at home [65, 66]. Although this practice would improve convenience for patients, it would also lead to many security problems which would need to be solved by establishing new regulations [67]. The final problem relates to printing accuracy. At present, 3DP is rarely used for pharmaceutical preparations. One of the reasons involved in the injection is that the printing accuracy is low, which cannot reach the ideal cell and molecular level. Moreover, printing sophisticated drug delivery vehicles is difficult [68, 69]. With the in-depth study of new materials and continual improvements in 3DP technology, the applications of 3DP technology in preparation design and engineering are expected to advance to new stages.

4. CONCLUSION

With 3DP technology, not only the speed, location and time of drug release, but also the dose can be controlled accurately, with high printing flexibility. These characteristics can also be applied to the fields of traditional Chinese medicine and pediatrics. Several limitations exist in manufacturing preparations with complex structures through traditional preparation technology. The “monarch, minister and assistant envoy” concept used in traditional Chinese medicine compound preparations makes the accuracy of the drug-release sequence and content in compound preparations particularly important. Traditional preparation methods may be inadequate, e.g., for rare or toxic medicinal materials that must be used in small quantities. At present, the accuracy of industrial 3D printers generally exceeds 0.1 mm. Printing traditional Chinese medicine preparations can fully meet clinical expectations for microquantities. In addition, 3DP technology can solve problems such as the inconvenience of carrying and storing traditional Chinese medicine preparations, and poor patient compliance. Patients could follow doctors’ orders to print traditional Chinese medicine powders or effective component extract powders into personalized preparations to treat their diseases.

Moreover, 3DP technology has a unique advantage in pediatric medication, because it can ensure that children in different growth stages receive accurate drug dosages, and can enable individualized dosages of highly active drugs. The appearance of tablets can also be accurately controlled. With color 3DP technology, preparations with specific colors and shapes can be printed. Cartoon animal tablets can also be printed in shapes that children like, to greatly improve patient compliance in clinical pediatric medicine. In addition, personalized drug administration benefits may include printing a variety of drug compositions, or combining a variety of drugs that patients must take into a single daily dose, to facilitate compliance and provide convenience, particularly for older patients. Compliance among children has long been a bottleneck in preparation research, and the differences in the pharmacokinetic parameters of children in different growth stages also affect the development of pediatric preparations. At present, the practice of halving adult dosages for children is far from meeting the increasingly diverse drug-use needs. The problems of individualization, compliance and accuracy in pediatric drug administration must urgently be solved.

Although 3DP technology still faces many technical and regulatory challenges [70], we believe that further developments will provide favorable solutions to the existing problems. Furthermore, 3DP is expected to bring new opportunities and hopes for advances in medicine, and to accelerate the arrival of the era of personalized, intelligent drug delivery.

CONFLICTS OF INTEREST

There are no conflicts of interest.

REFERENCES


Review


