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Review Article

The era of digital pharmacy. 3D printing - realities and perspectives

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Abstract

3D printing is an innovative technology for building three-dimensional objects by laying down successive layers of material under the control of a computer software. It is entering pharmacy mainly because of its revolutionary potential to provide individualized dosage forms that meet the needs of each patient, due to the possibility to produce objects of many different sizes and shapes. An important aspect of personalized 3D tablets is the possibility to include several active substances in one dosage form, which would reduce the daily number of medications and the frequency of their administration and improve patient compliance. Another advantage of 3D printing is the possibility of producing small batches or even individual drugs for each patient. Despite the many advantages, 3D printing has several technological challenges to overcome before it becomes widely applicable in pharmacy. Five basic technologies are currently applied in pharmaceutical practice: powder-based printing, selective laser sintering, stereolithography, extrusion moulding printing, and electrohydrodynamic 3D printing. This article reviewed development, research focus, and prospects of each technology respectively.

Keywords

Powder-based printing, selective laser sintering, stereolithography, extrusion moulding printing, electrohydrodynamic 3D printing

Introduction

The three-dimensional (3D) printing is an innovative technology for building three-dimensional objects by laying down successive layers of material under the control of a computer software. A main feature of this method is the possibility for production of complex geometric shapes. For this reason, it has already steadily entered the engineering sciences and is about to revolutionize medicine and pharmacy (Alhnan et al. 2016).

The terms "three-dimensional printing", "additive printing", "additive manufacturing" and "rapid prototyping" are used as synonyms for 3D printing. In conventional manufacturing methods, the desired shape of the object is achieved by removing excess material from a monolithic block, hence the retronyms "subtractive manufacturing" and "subtraction technology". "3D printing" is used to describe various methods in which objects are built layer by layer, hence the term "additive manufacturing" (Norman et al. 2017; Roopavath et al. 2017).

In summary, the 3D printing process proceeds as follows: the object to be printed is drawn three-dimensionally using Computer Aided Design (CAD) software and exported as a stereolithographic image (stl. file). This file "cuts" the 3D object into a series of 2D images that the printer prints on top of each other to create the specified complex 3D object. Therefore, the main components of 3D printing technology can be divided into three groups:

1) hardware (the 3D printer itself); 2) software (to communicate with the hardware and to convert the images drawn by CAD into stl. files that are recognized by the printer, and 3) materials used for printing (Roopavath et al. 2017).

3D printing is entering pharmacy mainly because of its revolutionary potential to provide individualized dosage forms that meet the needs of each patient (Gaisford 2017). The need for personalized medicine emerges from the extremely complex structure of the human organism. Various factors such as age, sex, health status and expression of certain genes influence the pharmacokinetics and pharmacodynamics of drug molecules. For this reason, different individuals require different dosage regimens or dosage forms, which are not always available (Awad et al. 2018). This is notably valid for paediatric and geriatric patients. Dosage requirements in these groups change dynamically, in the former due to rapid changes in the physiological and metabolic functions of the body, and in the latter due to pathologies in the gastrointestinal tract and renal clearance. In elderly patients, polypharmacy and comorbidities should also be considered (Alomari et al. 2015). Until now, various methods of personalized dosing have been used in pharmaceutical practice, but the paradigm of individual drugs, in which the dose, the dose combination or the active substance itself are tailored to the patient's genetic profile, is not yet fully understood (Gaisford 2017).

Of course, pharmaceutical technology has so far offered a variety of mechanisms for individualizing the dose. One of the classic approaches is the use of liquid dosage forms – individual dosing can be easily accomplished by taking different volumes, usually with the help of a dosing device included in the product packaging. However, the risk of dosing inaccuracy should not be overlooked. This also applies to the most common approach for solid dosage forms - splitting "scored" tablets in half. There is also data about modern approaches such as dosing devices for multiparticulate pellet systems, Solid Dosage Pen, and oral films that can be cut into individual segments allowing for individual dosing (Wening and Breitkreutz 2011; Alomari et al. 2015).

An approach for individualizing the dose is also inkjet printing that can be considered a precursor to 3D printing. The idea generated from printers that recreate digital images on paper by dripping tiny droplets of ink. The technology has been adapted for pharmaceutical purposes as the ink is replaced by a solution of an active substance and the paper – by edible sheets called substrates (Alomari et al. 2015). The dose variation can be achieved by changing the number of printed layers for a given area or by increasing the print area itself. One of the advantages of this technology is the good control over the precision of the dose combinations and the release of the active substance. It is very suitable for the production of low-dose drugs, especially those with doses in the range of micrograms (Alomari et al. 2015; Alhnan et al. 2016).

3D printing is a very promising platform for individual dosing because, compared to the approaches described so far, it has the flexibility to produce objects of many different sizes and shapes. This advantage is the subject of scientific research aimed at modifying the dose by changing the size, surface area or the infill degree of the printed tablet. This is especially necessary for paediatric patients, which are characterized by both large variations in prescribed doses and swallowing difficulty (Alhnan et al. 2016). If 3D printing is combined with 3D scanning technology that captures the anatomical features of each patient, it can be used for individualized medicinal products (Muwaffak et al. 2017; Liang et al. 2018). Studies are published describing pre-scanned products printed according to the shape of the patient's nose (Goyanes et al. 2016; Muwaffak et al. 2017), as well as dental protectors made from a combination of polylactic acid and polyvinyl alcohol (Liang et al. 2018), and intrauterine implants (Genina et al. 2016; Holländer et al. 2016).

An important aspect of personalized 3D tablets is the possibility to include several active substances in one dosage form, which would reduce the daily number of medications and the frequency of their administration and improve patient compliance (Khaled et al. 2015a). A number of studies have been published related to this topic, for example tablets, containing combinations of chlorpheniramine maleate and diclofenac (Katstra et al. 2000), rifampicin and isoniazid (Genina et al. 2017), or paracetamol and caffeine (Goyanes et al. 2015b). The therapeutic efficacy of fixed-dose combinations in cardiovascular disease is well established. However, applying these combinations, individual patient characteristics and needs may be overlooked. In this regard, 3D dosage forms containing three (captopril, nifedipine and glipizide) (Khaled et al. 2015a), five (hydrochlorothiazide, ramipril, acetylsalicylic acid, pravastatin, and atenolol) (Khaled et al. 2015b) active ingredients would be appropriate for application.

In addition to dose variation, different types of additive printing also demonstrate a wide range in drug release. On the one hand, powder-based technology achieves revolutionary rapid disintegration. An example of this is the first FDA-approved 3D printed drug product, Spritam, produced using the company's patented Aprecia ZipDose technology. On the other hand, by Fused deposition modelling (FDM) technology could be achieved immediate (Arafat et al. 2018; Ehtezazi et al. 2018) or extended (Goyanes et al. 2015c; Pietrzak et al. 2015) and delayed (Goyanes et al. 2015d; Genina et al. 2017) drug release.

Another advantage of 3D printing is the possibility of producing small batches or even individual drugs for each patient. The compact design and simplified software of some printer models make them suitable for positioning close to where pharmaceutical care takes place (in hospital and open-label pharmacies) (Alhnan et al. 2016). This would allow personalized e-prescriptions to be fulfilled in pharmacies (Awad et al. 2018). On the other hand, the rapid production of small batches of medicinal products and medical devices would significantly reduce research costs (Goyanes et al. 2018) (Fig. 1).

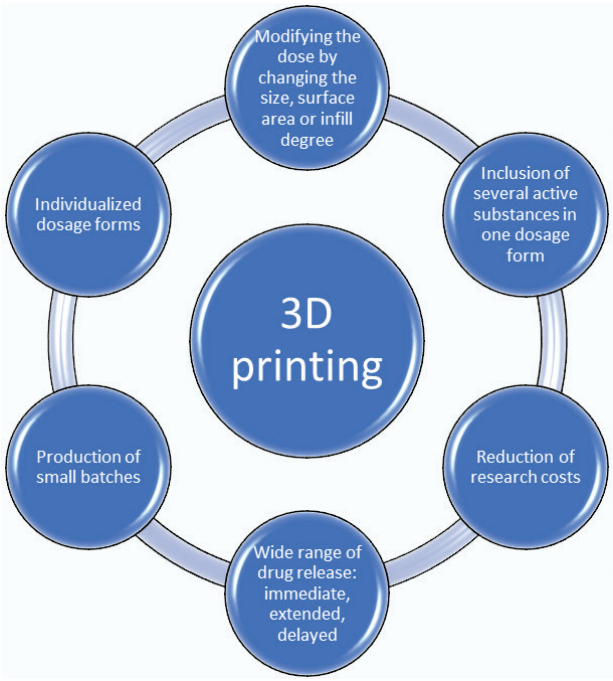

Figure 1. Advantages of 3D printing.

Despite the many advantages, 3D printing has several technological challenges to overcome before it becomes widely applicable in pharmacy. For example, in extrusion methods and powder-based technology, the construction of successive layers of material is carried out by means of nozzles. Their clogging has a negative impact on the reproducibility of the process (Alhnan et al. 2016; Norman et al. 2017). In powder-based technology and selective laser sintering, the removal of the remaining non-bonded material from the powder bed must also be considered, therefore this type of printer can only be located in special premises (laboratories or production facilities) but not in open-type pharmacies (Alhnan et al. 2016). For technologies involving the presence of a solvent (extrusion of semi-solid material and powder-based technology) an additional drying stage is also necessary, which leads to prolongation of the work process. In addition, both methods yield fragile structures that do not meet the pharmacopoeial requirements for tablet friability (Yu et al. 2009). Certain limitations in the choice of excipients must also be considered. For example, only photopolymerizable oligomers (Fuh et al. 1999) can be used for stereolithography, and thermoplastic polymers must be used for Fused deposition modelling (Awad et al. 2018).

3D printing technologies applied in pharmaceutical practice

Five basic technologies are currently applied in pharmaceutical practice: powder-based (PB) printing, selective laser sintering (SLS), stereolithography (SLA), extrusion moulding printing (EMP), and electrohydrodynamic 3D printing (EHD) (Cui et al. 2021) (Fig. 2).

Powder-based 3D printing technology

Powder-Based (PB, also called Binder Jet) 3D printing technology was first developed at the Massachusetts Institute of Technology. During the printing process a fine layer of powder particles (by means of a powder bed or a powder spreading mechanism) is spread and selectively bonded by supplying droplets of liquid from an inkjet or piezoelectric printing head (Katstra et al. 2000) (Fig. 3).

This technology is applied in the manufacture of implants (Huang et al. 2007), bone scaffolds (Zhou et al. 2014), solid dosage forms (Katstra et al. 2000), in the cosmetic industry (Vanderploeg et al. 2017) and in plastic surgery (Chae et al. 2015). Using PB printing technology successfully had been produced tablets with complex dissolution profiles, e.g., extended, or dual-pulsatile, as well as first-order kinetics (Alhnan et al. 2016). Recently, this technology has also been used to produce rapidly disintegrating tablets, as an example is Spritam (levetiracetam) - the first FDA-approved printed dosage form. Spritam tablets consist of loosely bound powder particles that quickly disintegrate in the oral cavity in the presence of very small quantity of liquid and

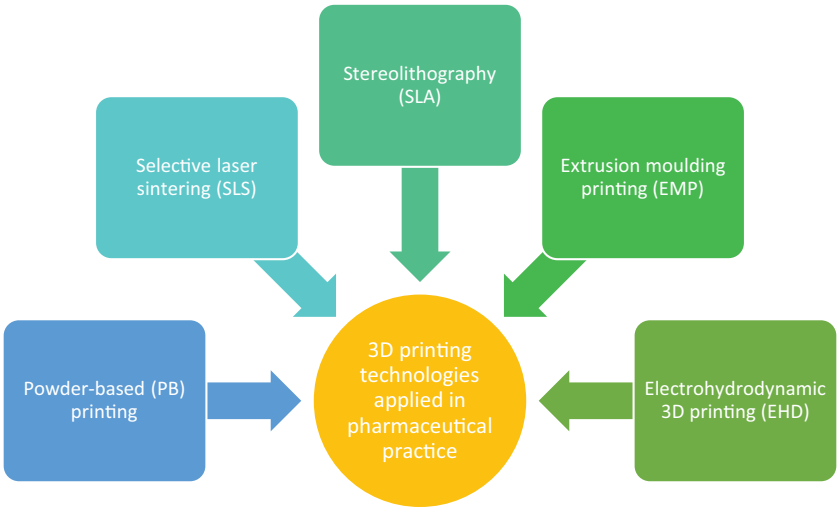

Figure 2. 3D printing technologies applied in pharmaceutical practice.

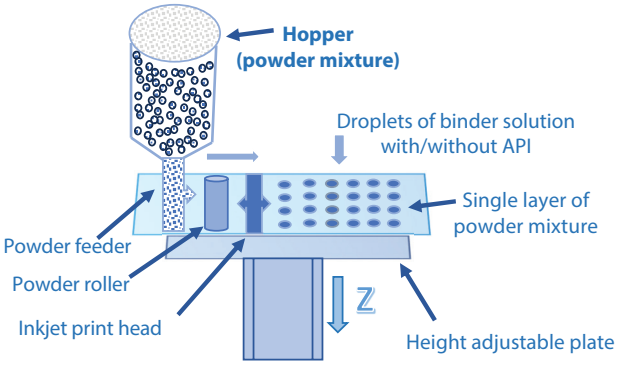

Figure 3. Powder-Based 3D printing.

are therefore classified as orodispersible. The dose of levetiracetam varies between 250 and 1000 mg. Practically, it is very difficult to incorporate such a large amount of active substance into orodispersible tablets, which makes this method valuable and unique (Gaisford 2017).

As already mentioned, PB 3D printing technology requires the use of powder mixture and a binder solution in order to produce printed products. Therefore, the properties of the powder mixture and the binder solution would directly influence the properties of the final product, such as mechanical strength, surface finish, disintegration time, etc. The powder specific properties that influence the quality of the final product are particle size distribution (Lu et al. 2009; Gentzler et al. 2015; Goole and Amighi 2016; Mostafaei et al. 2019; Bai et al. 2020; Dini et al. 2020), powder flowability (Bai et al. 2020; Sarkar et al. 2017), packing density (Lu et al. 2009; Zhou et al. 2014; Goole and Amighi 2016; Bai et al. 2017; Ke and Bose 2018; Averardi et al. 2020; Kamba et al. 2000; Sen et al. 2020; Du et al. 2021), powder-binder interaction (Hapgood et al. 2002; Zhou et al. 2014; Liu et al. 2017; Bai et al. 2019; Reeves and Lawal 2021).

Except the advantages of PB printing technology, such as the possibility for production of fast dissolving tablets, precise drug loading, personalization of drug products and scalability, this method is characterized by some limitations. The main are absence of regulatory guidelines and need for optimization of the printing process.

Selective laser sintering (SLS)

Selective laser sintering was first proposed by C.R. Dechard in 1989 in the University of Texas Austin and got patent in 1990 (Beaman and Dechard 1990; Mazzoli 2012). SLS is a technology similar to PB 3D-printing technology, but the welding of powder particles is achieved by using a laser beam. The sintered particles produce the 3D printable object, while the ones that are not sintered remain as part of the support structure and their removal requires an additional operation (Gaisford 2017). This is a standard technique for printing metals, but other materials could also be used, such as polyamides, polystyrenes, or polycarbonates (Alhnan et al. 2016). SLS has been applied in tissue engineering as well as in a number of non-medical sciences (Tan et al. 2003). Since this method does not apply solvents, it has been considered as promising for future developments in pharmaceutical technology (Gaisford 2017). At present, the SLS studies are focused mainly on material development, process optimization and different applications. The process optimization is crucial due to the fact that the laser power and the scanning speed affect in great extent the sintering process (Dastjerdi et al. 2017; Lee et al. 2017; Mokrane et al. 2018). Development of new materials is also important based on the fact that the existing polymer materials are limited and usually need improvement of their properties by use of various additives (Bai et al. 2013; Bai et al. 2015; Salmoria et al. 2018; Yan et al. 2018). The number of additives used increases with the time which leads to application extension in medicine, especially in tissue engineering and medical implants (Eosoly et al. 2010; Yuan et al. 2019).

Discussing SLS, high-speed sintering (HSS) should also be mentioned. This is a novel technology patented by Professor Neil Hopkinson at Loughborough University in 2003 (Lavecchia 2019). The main materials used in this method are nylon and some elastomers (Ellis et al. 2014a, 2014b). During the process, the nozzle deposits a radiation absorbing material upon the polymer powder surface. HSS uses infrared lamp instead of the laser used in SLS, which leads to a reduction of the device's price. Another advantage is that the printing speed of HSS is improved in a great extent compared to SLS, which is due to the fact that the infrared lamps heat a large printing area.

Stereolithography (SLA)

Stereolithography applies photopolymerization of resins with the help of a laser. The resin is placed in a container and the laser is aimed at a specific depth in this container. Moving, the laser creates parallel lines that form the first layer of the built object. The resin tank is then moved, the operation is repeated, and a second layer is built up, etc. (Fig. 4).

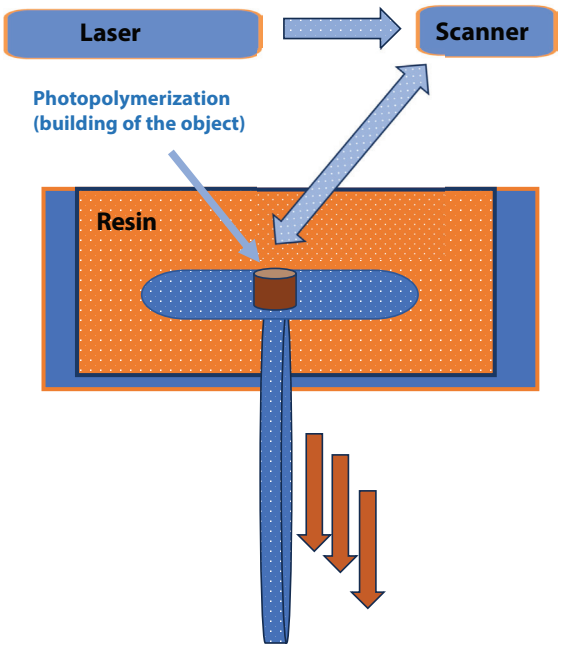

Figure 4. 3D Printing by Photopolymerization (SLA).

A simple method for incorporation of the active substance is dissolving or dispersing it in the resin (Gaisford 2017). Both solid and powder-based materials used in SLA are thermoplastic polymers, such as polyamide (PA), polylactic acid (PLA), and acrylonitrile butadiene styrene (ABS). SLA is rarely used for the preparation of oral dosage forms because most photopolymerizable materials possess serious toxicity, fragility, or vulnerability to light exposure. Recent material developments are gradually reducing these limitations. A study was published describing the application of SLA for incorporation of an active substance (acetylsalicylic acid) into polyethylene glycol diacrylate (PEGDA) medical devices. Complete drug release was observed within three hours. One of the advantages of using polyethylene glycol diacrylate for printing is the ability to directly print hydrogels (Vehse et al. 2014).

Extrusion methods

3D printing by extrusion is a general term that combines processes in which the source material passes through an opening, thus forming fine semi-solid filaments, that when solidified, build a three-dimensional object. Depending on whether the initial material is in semi-solid state or in the form of rigid, thermoplastic polymer filaments, the method is classified as semi-solid extrusion and fused deposition modeling (Alhnan et al. 2016; Awad et al. 2018).

In Semi-solid extrusion, the initial material is in the form of a gel or a paste with a viscosity suitable for printing and is loaded into the syringe-like device of the 3D printer. The semi-solid mixture is applied layer by layer until the software-defined model is built. Characteristic of this process is that an additional step is required, namely drying (Khaled et al. 2014; Khaled et al. 2015a). The applicability of semi-solid extrusion in pharmaceutical technology was initially confirmed with the production of bilayer guaifenesin tablets, which demonstrated release profiles similar to the licensed product containing the same active substance (Khaled et al. 2014). The maximum number of substances included so far in a 3D printed dosage form is five, and each compartment is characterized by different and independent of the others unchanged or modified drug release (Khaled et al. 2015b).

An indisputable advantage of semi-solid extrusion is that it applies low temperatures, which is suitable for thermosensitive substances. On the other hand, however, the presence of solvents is a risk factor for the stability of the dosage form. Also, during the process of drying, a shrinkage of the objects is observed, which leads to deformation. Other disadvantages are the low printing resolution and the erasability of the tablets obtained, which do not meet the pharmacopoeial standard (Alhnan et al. 2016).

Fused Deposition Modeling (FDM; Fused Filament Fabrication, FFF) was patented by Scott Crump and his wife in 1989 (Awad et al. 2018) (Fig. 5).

In this method, the initial material is a thermoplastic polymer, and is softened or fused into the nozzle of the print head, which applies it to the build platform, moving

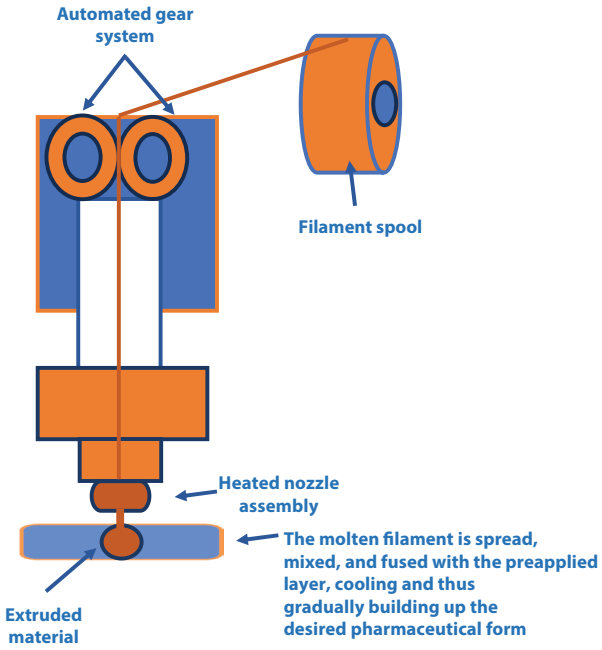

Figure 5. 3D printing by extrusion (FDM).

along the x, y, z axes. The temperature of the platform is maintained by the temperature of the polymer, which allows it to harden quickly. After building the first layer, some printer models move the build plane down the z-axis, while others move the print head up. In both cases, this makes it possible to deposit the next layer of material, then another, and so on, until the structure is built according to the specified computer model (Gaisford 2018). It is currently the most widely used 3D printing technology, therefore it will be discussed in detail in the present review article.

Due to its unique characteristics, FDM printing can easily be adapted to produce almost any solid dosage form with varied dissolution profiles (Awad et al. 2018; Trenfield et al. 2018). Printed drugs are characterized by a very precise spatial distribution of the active substance and the excipients, which is hard to achieve by most of the conventional technologies (Goyanes et al. 2015b). Using FDM solid dosage forms with unchanged (Arafat et al. 2018; Ehtezazi et al. 2018), sustained (Goyanes et al. 2015c; Pietrzak et al. 2015) and delayed (Goyanes et al. 2015d; Genina et al. 2017) drug release as well as drug-loaded medical devices (drug-eluting medical devices) (Muwaffak et al. 2017; Liang et al. 2018) could be prepared. Due to the fact that a wide range of polymers soluble in physiological medium with different pH (e.g., methacrylic acid derivatives) could be used, this technology has the potential to produce targeted drug delivery systems (Pietrzak et al. 2015).

The pilot studies on the application of FDM in pharmaceutical technology were published in 2014, with the manuscript emphasizing the influence of printer settings on the active substance release profiles. An example of such a setting, which is a critical process parameter (CPP), is the infill percentage of the tablet. A dependence was deduced that tablets with a lower infill percentage demonstrated a faster release. This is logical and is mainly due to the

different swelling of the polymer at different tablet densities (Goyanes et al. 2014). An interesting phenomenon is that tablets with lower infill and lower density are lighter than the water and a "floating effect" occurs. According to some authors, this phenomenon could be used for increasing the residence time of the tablets in the stomach and thus leading to prolongation of their action, so theoretically, this method could be used for preparation of sustained-release dosage forms (Chai et al. 2017). However, this statement is controversial, because as mentioned earlier, most studies state that tablets with a lower infill tend to have a rapid/unchanged release, and those with a higher percentage infill tend to have a prolonged release. A more realistic application of the "floating" tablets would be the inclusion of active substances with weak basic properties because their residence time in the acidic gastric medium would be longer which could increase the bioavailability. When analyzing the degree of dissolution of such dosage forms using the paddle method, it is important to apply some of the modifications described in the literature, for example, to use sinkers that hold the tablets at the bottom of the tube (Awad et al. 2018).

An alternative method for increasing the dissolution rate of the active substance from 3D printed tablets is incorporation of channels in their structure in order to increase the total surface area (Sadia et al. 2018). A similar effect of rapid fragmentation and release of the active substance without the inclusion of a disintegrant could be also achieved for printed tablets containing internal cavities (Arafat et al. 2018). Control over the degree of dissolution can also be achieved by printing mesh structures (tablets without printed top and bottom layers) of varying density. It is almost impossible to achieve such complex structures by any other technological approach (Korte and Quodbach 2018a).

Another major mechanism for influencing the release rate of matrix tablets prepared by FDM is changing the mass: surface area ratio. A possible way to achieve this is by changing the mass of the tablet. Smaller tablets have a proportionally larger surface area and therefore demonstrate faster release (Skowyra et al. 2015). Such experiments have also been conducted with varying the tablet shape. A comparison of the release profile of tablets with five different geometric shapes (cube, pyramid, cylinder, sphere, and torus) confirmed that proportionally smaller surface area resulted in slower release (Goyanes et al. 2015c).

Although often underestimated, the shape and colour of medications are essential to patient compliance and hence to the effectiveness of the therapy. Data from an open-label randomized study indicated that patients had a marked affinity for certain forms, with toroidal being the most preferred, and the diamond and spherical shapes with the least approval. The same study indicated that, in terms of size, capsules of sizes 2 and 3 were the most preferred. In terms of color, however, FDM does not have the capacity to provide the same variety as PB technology (Goyanes et al. 2017). Ease of dose adjustment makes FDM dosage forms particularly suitable for use in preclinical and clinical studies. In addition, a product with suitable size and shape for any animal model can be easily printed, for example caplets size 9 for rats. 3D printing eliminates the need for large batch production and thus minimizes the costs in this phase (Goyanes et al. 2018).

Fused deposition modelling, as well as other 3D technologies, enables the inclusion of several active substances in a single dosage form. A possible mechanism to achieve this is "dual" FDM printing, where the printer is equipped with two nozzles that feed different filaments. So far, experiments were made to obtain "multilayer" tablets, where layers of polymer containing different substances were successively applied, and bilayer tablets, where the core of the tablet was composed of one polymer and the outer layer of another. For multilayer tablets, the release depends solely on the properties of the polymer used, while for bilayer tablets the solubility of the outer layer is rate-determining (Goyanes et al. 2015b). Another way to combine several active substances, even if they are chemically incompatible, is loading them into hollow multi-compartment 3D printed capsules. Due to the possibility of capsule compartments to be printed from different material and/or with different wall thicknesses, the release of each drug substance could start at different time (Maroni et al. 2017; Melocchi et al. 2018).

One of the main technological challenges to additive printing by FDM is the inclusion of the active substance in the filament. There are two main approaches to achieve this. The first one is impregnation of a commercial filament in a saturated organic solution of the active substance; thus, the drug is loaded by passive diffusion. The second approach for inclusion of the drug is during the extrusion of the filament (Awad et al. 2018). In the literature could be found also a single description of a third approach - by casting short filaments in a silicone mold (Costa et al. 2015). Several experiments applying the first approach (Goyanes et al. 2014; Goyanes et al. 2015a; Skowyra et al. 2015) were published, with the first study by Goyanes and co-workers using commercial filaments based on polyvinyl alcohol and fluorescein as a model substance and demonstrating that the dissolution degree could be modified by the degree of infill of the tablets (Goyanes et al. 2014). Subsequently, the possibility of obtaining dosage forms with modified release was also proved (Goyanes et al. 2015a; Skowyra et al. 2015). The main problems of this method are the high printing temperature of the commercial filaments and the low loading efficiency of the active substances (Awad et al. 2018).

Hot melt extrusion, which is the second main approach for drug loading of filaments, is a widely used process in the pharmaceutical industry to obtain solid dispersions, and a mechanism for increasing the solubility of poorly soluble substances (Patil et al. 2016). The first step of the process includes preparation of the mixture for extrusion. The active substances and the excipients are weighed, sieved, and homogenized. Thus, the obtained

homogeneous mixture is placed in a hopper, and is fed into the cylinder of the extruder. Then it is subjected to a combination of high temperature and pressure that causes its melting. Using rotating screws, the molten material is pushed through a metal nozzle and formed into long filaments. The filaments thus obtained are allowed to cool and subsequently sealed to avoid water absorption (Awad et al. 2018). The first successfully extruded filaments were obtained using ground commercial filaments (Goyanes et al. 2015c). Subsequently, small laboratory extruders produced polymer filaments using polymers commonly applied in the pharmaceutical industry (Pietrzak et al. 2015; Genina et al. 2016; Melocchi et al. 2016). Research has recently been published, that used an industrial-sized extruder (Zhang et al. 2017; Korte and Quodbach 2018b), and Korte and Quodbach successfully demonstrated a systematized approach for production of 3D printing filaments in a production setting through a continuous process (Korte and Quodbach 2018b).

Electrohydrodynamic 3D printing (EHD)

EHD 3D printing is a promising technique, which has gained much attention in the recent years (Ru et al. 2014; Onses et al. 2015). This method applies an electric field to induce ink ejection onto a substrate using a conductive nozzle. EHD technique can produce fibers with diameter in micrometre scale, which is one of the main advantages. EHD 3D printing is successfully applied in fabrication of tissue-engineered scaffolds (Tan and Zhou 2020; Rahmati et al. 2021), tendon tissue engineering (Wu et al. 2017; Hochleitner et al. 2018), creation of blood vessels (Jungst et al. 2019), bones (Martine et al. 2017), corneal stroma (Kong et al. 2020), tumour models (Nie et al. 2020). In spite of these numerous applications, EHD 3D printing technique is characterized by a significant disadvantage, namely incapability of producing scaffolds with thickness larger than 7 mm (Wunner et al. 2018). Another disadvantage is the limited number of materials appropriate for EHD 3D printing, PCL being the dominant biomaterial. However, PCL undergoes plastic deformation even at small strains (Hochleitner et al. 2018) and in order to overcome this problem PCL-based materials are synthesized and used in EHD printing. Although the significant efforts that are necessary to overcome these limitations, EHD 3D printing will play a substantial role in tissue-engineered scaffolding in the future.

Summary

In this paper a concise review on the 3D printing technology was carried out. This is an innovative technology for building three-dimensional objects by laying down successive layers of material under the control of a computer software. Five basic technologies are currently applied in pharmaceutical practice: powder-based printing, selective laser sintering, stereolithography, extrusion moulding printing, and electrohydrodynamic 3D printing. This article reviewed development, research focus, and prospects of each technology respectively. 3D printing is entering pharmacy mainly because of its revolutionary potential to provide individualized dosage forms that meet the needs of each patient, due to the possibility to produce objects of many different sizes and shapes. This advantage is the subject of scientific research aimed at modifying the dose by changing the size, surface area or the infill degree of the printed tablet. An important aspect of personalized 3D tablets is the possibility to include several active substances in one dosage form, which would reduce the daily number of medications and the frequency of their administration and improve patient compliance. Another advantage of 3D printing is the possibility of producing small batches or even individual drugs for each patient.

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Competing interests

The authors have declared that that no competing interests exist.

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