REVIEW ARTICLE

3D Printing Technology: A Contemporary Revolution in Drug Development

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Abstract

As a recently developing technology, three-dimensional (3D) printing has a lot of potential in the pharmaceutical sector and can cater patients and the pharmaceutical industry with innovative approaches. This technology allows for the accurate creation of dosage forms, which can help with drug product design. It also facilitates treatment for patients, such as individualized dosing, which can be used to treat particular disease states or patient groups. New approaches and techniques for creating unique medication delivery systems are made possible by the evolution of 3D techniques. The use of 3D printing technologies in the pharmaceutical industry is outlined in this paper, with special consideration devoted to the benefits of these technologies for attaining quick medication delivery, personalized drug delivery, compound drug delivery, and customizable drug delivery. This article also demonstrates the history, advantages, prospects, applications, constraints, and difficulties of 3D printing techniques in the area of developing pharmaceutical formulations. Pharmaceutical manufacturing is only one of many industries where the 3D printing (3DP) technique has had an important impact since its introduction in the early 1980s. Researchers and the public are becoming more interested in creating customized or individualized dosage forms as a result of the shifting horizons. The current work validates the viability of volumetric 3DP for quickly printing pharmaceutical items. This novel technology can enable the quick, on-demand manufacture of pharmaceuticals and medical equipment with further optimization.

Key words: 3D printers, 3-D printing, extrusion printing, selective laser sintering

INTRODUCTION

Engineer Charles Hull first proposed 3D printing, also known as additive manufacturing, in early 1980. In the 3D printing process, materials are placed one on top of the other to create an object. It builds up the printed layers, coating by coating to complete the production of a 3D object using a pre-designed 3D digital model. Due to the tremendous flexibility of 3D printing, material composition, and microstructure can be controlled locally. 3D printing is more affordable and time-efficient than traditional methods because it has significant benefits in generating extremely complex- and custom-designed objects.[1] Pharmaceutical 3D printing has been the subject of extensive study and significant development. The majority of research since then has focused on investigating and improving 3D printing techniques for pharmaceutical applications, although in recent years, there has been a significant advancement in the development of commercial-scale capabilities. The FDA's approval of the first 3D-printed drug and its commercial-scale production proved that it is possible to manufacture medications on a big scale utilizing 3D printing techniques. Regarding the 3D printing methods applied to the creation of medication dosage forms, these methods can be roughly divided into four groups: systems based on extrusion, powder, liquid, and sheet lamination. Highlights these categories, the many approaches that have been used within the categories, as well as some benefits and drawbacks of each technique.[2] The 1980s saw the emergence of three-dimensional printing (3DP), a growing fabrication technique. Digital model creation and

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evolution, digital slicing, G code file discussion, and 3D printer production are the four key components of 3D printing technology. Comparing this technique to conventional manufacturing methods reveals competitive advantages in the design of complicated structures and the production of tailored medication delivery systems. The industries of aerospace, mechanical manufacturing, construction, and biomedical engineering have all benefited significantly from the rapid development and wide-ranging uses of 3D printing techniques in recent years.[3] Pharmaceutical experts are increasingly concentrating their efforts on creating customized medications and three-dimensional printing preparations. Every year, more publications about 3D printing preparations are released, including numerous original studies and review articles that serve as excellent resources for further in-depth investigation. The pertinent research development on 3D printing technology, however, has to be updated and augmented over time because it is an emerging technology and its connected information gets updated and iterated frequently. This analysis highlights the most significant and recent 3D printing applications in the pharmaceutical industry, with a focus on prospects in drug delivery devices (DDD) systems and the main challenges that remain challenges of this technology.[4]

HISTORY OF 3D PRINTING

Figure 1 reflects the history of 3D printing.

CLASSIFICATION OF THE SEVERAL ADDITIVE MANUFACTURING METHODS USED IN THE PHARMACEUTICAL INDUSTRY

Figure 4 represents the steps involved in 3D printing.

IMPORTANT TECHNIQUE OF 3D PRINTING

Ink-jet (IJ)-based 3DP

IJ printing involves sprinkling a liquid binding agent onto a bed of powder material to form layers. This paste-like liquid binding agent, which is made up of excipients, solvents, and/or pharmaceuticals, is sprayed in specific movements, speeds, and sizes as droplets over a bed of powder. During deposition, the powder particles infiltrate the binder and assemble to form the first printed covering. This covering is now hardened or cured, after which powder particles are distributed over it by a recovering process utilizing a counter-rotating roller. The subsequent step involves printing this layer and using glue to connect it to the preceding layer. The previous stage is continued until the DDS has the appropriate geometry, at which point the de-powdering method is used to get rid of unbound loose powder that accumulates during printing.[6]

Extrusion-based printing technology

One of the most often utilized technologies is extrusion molding printing. Scientists working on formulations are quite interested in this technique. On account of the various molding materials, the extrusion molding printing technique may be broadly separated into fused deposition modeling (FDM) and semisolid extrusion molding (SSE).[5]

FDM

In FDM technology, drug-loaded polymers are heated to a critical state that transforms them into a semifluid state, and they are subsequently extruded from the printing nozzle following the model parameters.[7]

SSE modeling

According to the modeling software, SSE 3D printing technology, also referred to as pressure-assisted microsyringe extrusion technology, deposits the paste layer by layer on the printing platform using a syringe-based print head under pressure or screw gear rotation.[8]

Drop on powder printing (DOP)

DOP fuses the powder particles in a deposited powder on the tenets using droplets emitted from the print head. Layers of powder are used in the production process, and a roller spreads each layer uniformly across the construction platform.[9] The print head precisely ejects droplets comprising binders,

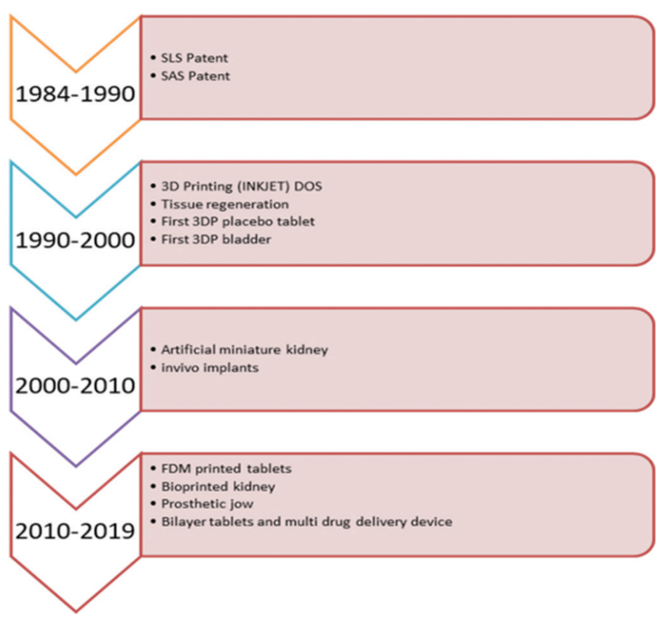

Figure 1: History of 3-D printing

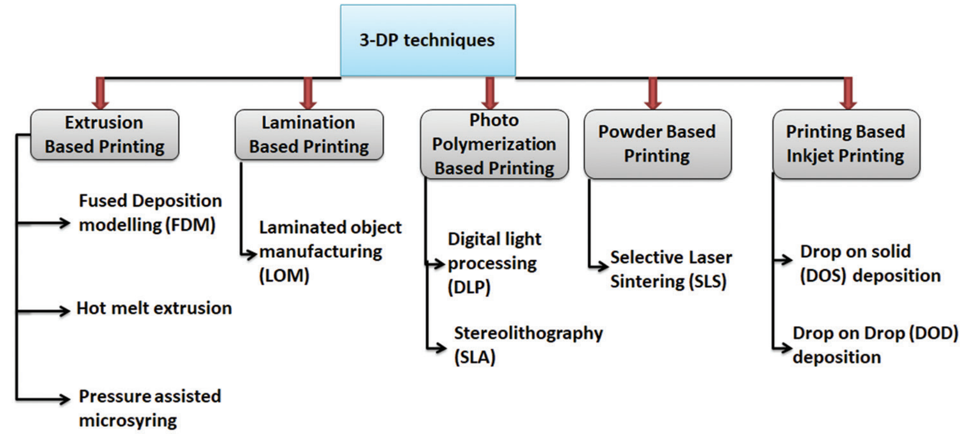

Figure 2: Classification of various additive manufacturing techniques employed in the pharmaceutical sector

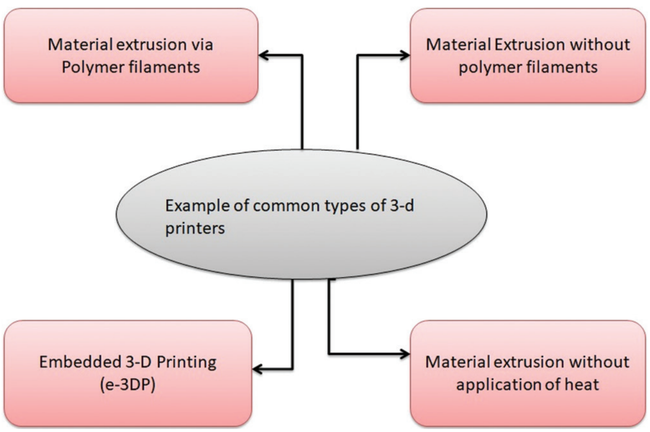

Figure 3: Some examples of common type of 3-D printers

such as PVP K30 and hydroxyl propyl methylcellulose, or active medicinal substances onto the powder bed by the predetermined pattern created in the computer.[10] The tenets are lowered one covering along the vertical axis after printing one layer before a new layer of powder from the feeding chamber is placed on top of the first layer. This procedure is carried out once more until all dosage forms have been used. The holistic structure is supported by post-processing, which comprises recovering unprocessed powder and getting rid of any remaining solvent.[3]

Selective laser sintering (SLS)

Similar to DOP, SLS is a powder-based processing method that uses a CO_2 laser beam rather than liquid binders to precisely sinter the chosen powder areas in each layer. SLS is a promising technique that provides a single-step, solvent-free 30 mm drug delivery approach with great precision. Without using liquid binders, SLS employs a laser to sinter the powder, cutting down on solvent evaporation time. To prevent stress and curl deformities, the temperature in the procedure chamber is typically maintained between 40⍰ and 50⍰, which is below the melting point of the raw material, during the printing procedure.[3] The concept behind SLS is similar to that of all powder bed 3D printing technologies in that layers of powder between 0.05 and 0.3 mm thick is spread out before being individually scanned by a laser beam. Although the un-sintered surplus serves as the support structure and is eliminated during post-printing processing, the sintered powder generates the component or final structure.

Stereolithography (SLA)

SLA was the first commercially viable technique and the forerunner of the 1986 invention of solid-free manufacturing. The selective photopolymerization of liquid photosensitive resins utilizing UV laser sources is the foundation for the SLA printing requirements. An initial thin coating of resin liquid containing medication and a photoinitiator is point by point scanned to polymerize. Due to polymerization between unreacted groups and resins in two adjacent sheets, the next sheet securely clings to the basic sheet when the depth of curing is just a little bit greater than the thickness of a single layer. Until the goals are met, this procedure is repeated. Removing extra resin and photoinitiator during post-processing is crucial for increasing mechanical strength and reducing resin toxicity. The integration of miscible components such as excipients and APIs that may not be polymerizable can be entrapped in the polymeric matrix following cross-linking, which is another benefit relevant to the field of pharmaceutics.[11]

EXAMPLE OF A COMMON TYPE OF 3D PRINTER[10]

Figure 3 Demonstrates some common examples of 3D printers.

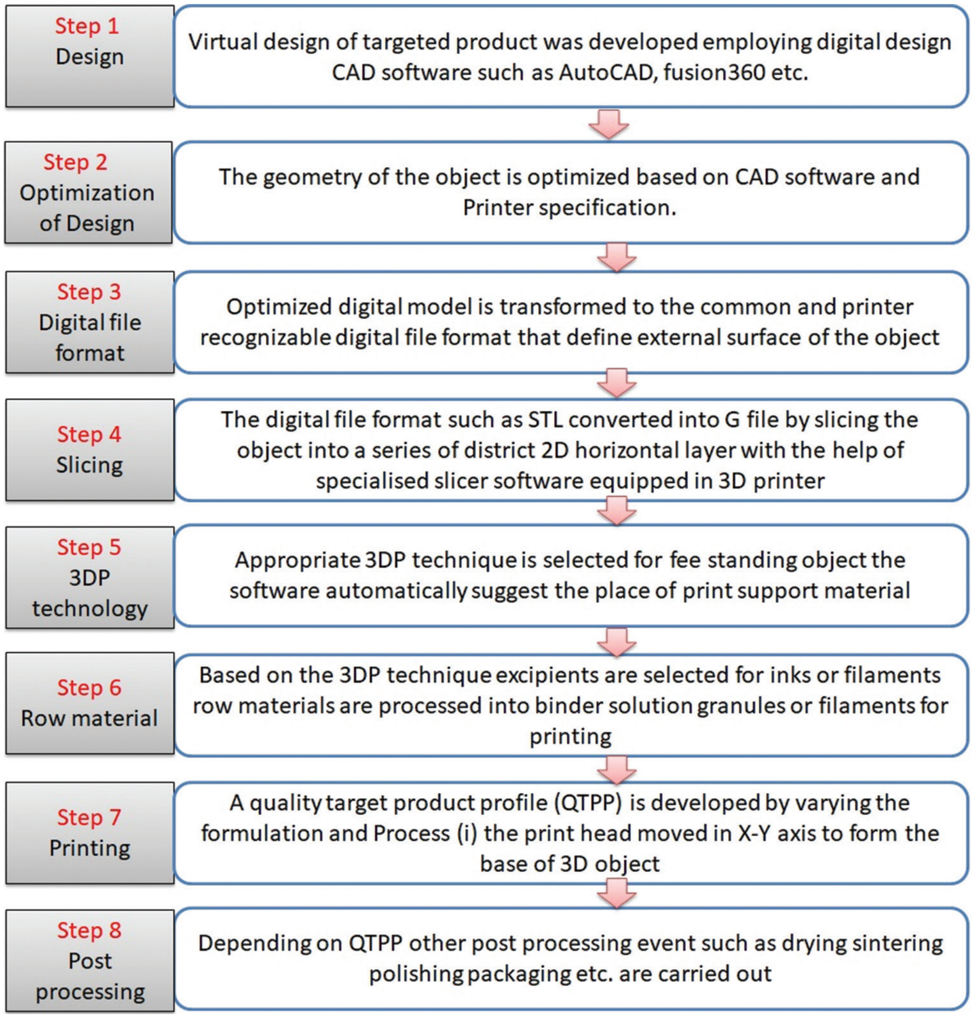

Figure 4: Common steps of 3D printing

APPLICATION OF 3D PRINTING TECHNIQUE IN HEALTHCARE AND PHARMACEUTICAL

Customizing dose forms opens the door for individualized treatment plans and is the pharmaceutical industry's most promising use of 3DP. To meet the needs of patients and specific patient populations, this is accomplished by creating suitable dosage forms, adjusting dosages and their combinations, or changing their release patterns. The pediatric cohort is a significant segment of patients that require dose modification, and the 3DP tends to help in giving dosage tensility to the needs of the kids. To correctly provide the patient's ideal dose, multiple formulations are developed using the 3DP technique because the therapeutic dose varies depending on the body weight and age of the children. With orodispersible film (ODF) formulations, it is accomplished by changing the quantity of liquid API delivered. These ODFs' size and form may be changed to further tailor the medications. To fulfill the patient's needs, the dose strength in different dosage forms can also be changed. For instance, by varying the printing size, a research printed theophylline tablets with a range of 60–300 mg using HME and FDM. Tablet splitting by hand or with a splitter has been tried recently to reach the correct dosage range. It has been demonstrated to be unsuccessful, nevertheless, because split pills do not adhere to pharmacopeial criteria. A research carried out by Zheng in which 3DP divided pills and split tablets were compared. Split 3DP tablets were proven to be more dependable, adaptable, and secure. In addition, the mixing and encapsulation of two separate drugs have been made easier by the fabrication of customized 3DP pellets or mini-printlets. Some of the fundamental factors that make the 3DP procedure the most patient-centric productive approach help customize the drug dosages, offering the best level of patient safety and efficacy.[6] Few formulations prepared by 3D printing technology are exhibited in Table 1.

Dentistry

3D printing has been widely used in the area of dentistry for a variety of purposes, from the development of surgical models for orthodontic treatment to the manufacture of replacement teeth.[13] As a result, it has been predicted that by 2020, this

Table 1: Formulations manufactured by 3D printing technology

Dosage form	Active ingredient	Excipients	Ref.
Caplet	1.Acetaminophen Caffeine 2. Budesonide	PVA filament	[20]
Capsule	Acetaminophen	PLA filament, HPC, PEG 1500, polyvinyl alcohol polyethylene glycol graft copolymer Brilliant Blue	[21]
Tablet	5-Aminosalicylic acid 4-Aminosalicylic acid	PVA filament, absolute ethanol	[22]
Tablet	Acetaminophen	PVA filament	[23]
Tablet	Fluorescein sodium	PVA filament, absolute ethanol	[24]
Implant T-shaped intrauterine systems	γ-Indomethacin γ-Indomethacin	Ethylene vinyl acetate Ethylene vinyl acetate	[25]
Implant	Levofloxacin	Poly(L-lactic acid), ethanol, acetone	[26]
Implant	Rifampicin Isoniazid	Poly(DL-lactic acid), methanol, acetone, purified water	[27]
Tablet	1.Chlorpheniramine maleate 2. Diclofenac sodium	1. Microcystalline cellulose, basic butylated methacrylate copolymer, ammonio methacrylate copolymer type A, Ethanol 2. Microcrystalline cellulose, spray dried lactose, methacrylic acid - methyl methacrylate copolymer, ammonio methacrylate copolymer type A, PVP K25, methanol, acetone, ethanol	[28]
Mucosal thin films	Cetirizine hydrochloride Diphenylhydramine hydrochloride Ibuprofen	Basic butylated methacrylate copolymer, ethanol	[29]

industry would be worth $3.1 billion. The product Invisalign, which consists of 3D-printed clear orthodontic devices that straighten teeth without the need for conventional metal braces, is the most commonly cited example of 3D printing in dentistry.[14]

3D printing of oral drug products

A variety of complicated formulas that are currently being made through 3D printing are ones that conventional manufacturing methods would find difficult to make. With this technology's high degree of adaptability, a wide range of drug solutions with customized release profiles and designs may be created, including controlled-release formulations, tablets that dissolve quickly, and drug combos that contain multiple medications.[15] Three key factors, notably the printlet shape, infill percentage, and polymer inclusion, may be changed to regulate drug release.[16]

Bioprinting tissues and organs

Tissue and organ bioprinting is becoming more and more popular. According to estimates, 20 patients in the USA alone pass away every day while waiting for an organ transplant. Although it is still too soon to solve the world's lack of organ donors, 3D printing still presents a viable answer.[17]

Innovative medical devices

The creation of custom medical gadgets is another application for 3D printing. For many patients who need particular structures, designing and printing bespoke implants and prostheses has currently replaced other techniques.[18] In particular, 3D printing has been extensively employed to create orthopedic medical devices, trauma medical implants, and dentistry components (e.g., knee and hip joint devices).[19]

CHALLENGES OF 3D PRINTING TECHNOLOGY

The pharmaceutical industry is seeing ongoing improvements in technology, which provides a variety of ways to satisfy the demands of tailored medication therapy. As technology advances, three-dimensional (3D) printing technology offers limitless potential for producing patient-fixed DDD systems and dosage forms. Furthermore, the fast-developing research on 3D-printed DDD has allowed us to identify several difficulties in the evolution and promotion of tailored DDD systems. The creation of DDD prototypes with varied levels of complexity made feasible by 3D printing demonstrates the feasibility of customizing pharmaceutical goods. Future printing technologies have the potential to enhance patient-specific medication therapy. The possibilities of 3D printing as a method for producing medical items will continue to be supported and strengthened by technology breakthroughs, fresh scientific ideas, multidisciplinary collaboration, and established regulatory requirements. With its intrinsic advantages of customizability and the capacity to contrive composite solid dosage forms with utmost clarity and precision, three-dimensional printing (3DP), a novel prototyping technique that has advanced over the past 35 years, has great potential to revolutionize the field of drug delivery. With complicated interior geometries, various medicines, and excipients, solid dosage forms with varied densities and diffusivities may be created using 3DP. Poorly water-soluble medicines, peptides, strong medications, the release of several pharmaceuticals, etc., may all be properly dealt with using 3DP. However, several issues limit the commercial market uses of 3DP, such as the choice of appropriate binders, excipients, and the pharmaco-technical characteristics of finished products. Where 3DP technology may effectively be integrated with a new drug delivery method, further process performance improvement is needed to address these problems (NDDS).[30] Different unplanned differences can be manufactured from the same 3D computer-aided design model even with computerized processes such as 3D printing, depending on factors such as but not short to age or standard of ink materials, altered slicer program-based printer settings, altered to the stage level or angle, and wearing of parts. This problem creates a need for rapid and practical analytical instruments to check the homogeneity, release profile, and concentration of each drug included to see if the desired medication was printed correctly. Some people propose employing prediction models or artificial intelligence to do the task. Others have suggested confirming numerous medication doses within polypills using a portable near-infrared spectrometer using calibration models generated by partial least squares regression.[31] For compliance with USP 795, it is necessary to determine the training requirements for technicians and pharmacists who will use 3D printers or advise patients on pharmaceuticals created by 3D printers. Drafters are those who have experience creating and printing models using 3D computer-aided design and some of them have particular knowledge in biological applications. To work as drafters in the industrial sector, these people normally need up to 2 years of instruction, while certain 3D modeling software is simple enough for those with no formal experience. To demonstrate their proficiency with 3D modeling standards, professional draughtsmen can get general certification from the American Design Drafting Association (ADDA) as well as certification in several other drafting specializations. Maybe the ADDA and pharmacy executives might collaborate to add pharmacy drafting as one of the certification specializations, developing best practices for 3D modeling and printing drugs in pharmacy environments.[12]

LIMITATIONS

Several 3D printing methods have been documented in the literature, including fused deposition modeling (FDM), binder deposition, inkjet printing, material jetting, powder bed fusion, photopolymerization, pen-based 3D printing, and molding. The development of customized solid oral formulations has recently drawn more study attention to 3D printing using FDM. However, the materials that can be processed by commercially available FDM printers are severely constrained to a small number of thermoplastic polymer types, which frequently are not materials that are approved for use in pharmaceutical dosage forms or ideal for improving the performance of poorly soluble compounds.[31] A lot of research is being done on this method, which has enormous promise for producing medicinal items. The fundamental issue in this area is the dearth of enough filaments made of materials of a pharmaceutical quality that are required to feed the FDM machinery.[30]

THE ADVANTAGES OF 3D PRINTING TECHNOLOGY IN PHARMACEUTICALS

Personalized medicine for special populations

Three-dimensional printing technology is highly flexible targeted medications may be printed using using-dimensional printing technology by modifying model parameters such as size, shape, or fill rate. Children's low-dose personalized medications can be created using 3D printing technology, and the appearance and flavor of the medications can be improved to increase patient compliance. For elderly patients who have trouble swallowing, 3D printing technology can create loose and porous preparations. In addition, specially shaped preparations can be printed or special symbols can be printed on the surface of the preparation to provide convenience for patients with visual impairment. For patients who take multiple medications at once, different drugs can be partitioned and combined into a single tablet to avoid errors or missed medications, which can increase the safety and effectiveness of the medication.[32]

Precise control of drug release

Tablets make up almost 70% of all dosage forms produced and are the most often utilized solid oral medication form. Tablet production is more affordable thanks to traditional manufacturing procedures, but preparation development has lagged due to their lengthy development timeframes and limited capacity to generate customized preparations on demand. In contrast to traditional pills, controlled-release preparations provide precise medication release control, reducing adverse effects, and boosting effectiveness. Nevertheless, because of their limitations, conventional manufacturing methods present more difficulties in the design and production of controlled-release preparations. Due to its tremendous flexibility, three-dimensional printing technology is particularly suited for the creation and production of complicated preparations. This is achieved by combining several medications, creating intricate models, and adjusting the printing parameters.[32]

THE BEST 3D PRINTERS TO CHOOSE FOR COMPOUNDING DRUGS

It is important to carefully consider your options when choosing the kind of 3D printer to employ in a pharmacy. Printers often provide a range of ink use options to allow for precise medication ink blending as needed for more predictable drug content. Because certain 3D printers have limitations on the kinds of materials that are relevant to printing ink, it is also crucial to take notice of the formulation and material types. To minimize the requirement to get permission for new materials, printers that may employ currently accepted pharmaceutical chemicals are preferable. Before the incorporation of 3D printing, it is improbable that normal pharmaceutical compounding will apply for approval of novel excipients.[33] The development of gastro-retentive tablets as ultra-long-acting extended-release dosage forms using new excipients has been the subject of several preclinical studies. These dosage forms must undergo appropriate clinical testing and receive regulatory approval before being used in clinical settings. It is also vital to keep in mind that some 3D printers will subject medication formulations to high temperatures that are inappropriate for drug formulations that are thermolabile. Not appropriate for thermolabile pharmaceutical formulations.[34] If compounding uses printers that are not meant for pharmaceutical processing, it is crucial to make sure that any parts that will come into touch with formulation ingredients are made of suitable materials, such as stainless steel. The finest printers in this regard for minimizing contamination are those that forbid direct contact between the machine and product ingredients risk.[12]

3D PRINTING IN PHARMACEUTICAL AND BIOMEDICAL

The use of 3D printing is expanding quickly across all industrial manufacturing sectors because of its benefits of improving production efficiency and decreasing the cost and quantity of faults by doing away with human error.[35] Given its substantial versatility and capacity to construct a variety of simple to complicated geometries, 3D printing has altered not just industrial production but also the emphasis on industrial automation. To produce high-quality medicinal products with improved process robustness, 3D printing is quickly transforming pharmaceutical products in the field of biopharmaceutical product development, where there is a dependence on creating medications using conventional manufacturing techniques. Moreover, the use of 3D printing in biomedical engineering to create medical tools for therapeutic and diagnostic purposes has been demonstrated to be beneficial.[36] We present an updated overview of the aforementioned 3D printing uses in this article, building on earlier assessments of medicinal product development and biological applications.[37]

CONCEPT AND PROCESS OF 3DP

When it comes to the production of pharmaceutical products, almost all 3DP procedures follow a similar basic workflow that entails several steps, including blueprint, optimization of design, the transformation of the design into a machine-readable 3D file format (standard triangle language or standard tessellation language, additive manufacturing file format, and 3D manufacturing format), slicing, 3DP technology selection, selection and processing of raw material, and production.[38]

3-D PRINTING MAKES BETTER THE WAY PATIENTS TAKE MEDICINE

Microneedles can also be produced using 3D printing. Microneedle technology is a painless approach to administering medicine through the skin. This is so that the medicine is released into the dermis without activating the pain nerve as a result of the microneedle's skin penetration.[19] Traditional methods for creating microneedles require several laborious, challenging processes, and coating methods may not completely ensure that the active coated layers are placed down precisely and uniformly. The use of 3D printing technology allows for the one-step fabrication of microneedles with a variety of structures, and the high resolution of the printer ensures that the array's details are accurate. It developed a transdermal patch that mimics a patient's nose using 3D scanning and SLA 3D printing.[39] The device's form is ideal for each patient's needs demonstrating the viability of 3D printing technology for creating microneedle patches by using 3D-printed microneedles for transdermal insulin administration. Painless transdermal medication injections could be possible using 3D-printed microneedles. They developed a collection of 25 tiny needles composed of fumaric acid that can pierce the skin without causing discomfort for the patients. Furthermore, using 3D printing technology, some researchers have created several novel medication administration methods. The group, under the direction of Priya Jain, created an implanted delivery system for tumor topical immunotherapy. The customized structure is created using 3D printing technology, and the implant's tiny pores are used to regulate the medication release rate. Continuous immunotherapy is made possible by this device's control of drug dispersion through physical and electrostatic nanometres. Developed the oral vaccine injection capsule MucoJet using 3D printing technology which can create gas after extrusion, launch the vaccine, and penetrate the oral mucosa to stimulate the immune system. It is a brand-new non-invasive vaccine administration technique that has been successfully tested in the oral cavity of rabbits.[1]

STEPS OF 3D PRINTING[40]

The Figure 4 represents the steps involved in conventional 3D printing method.

3-D PRINTING TECHNOLOGIES IN DRUG DELIVERY

The use of 3D printing technology to fabricate distinctive, innovative, and focused geometries adjusted with tailored drug release properties to generate personalized drug delivery profiles has been investigated for the creation of various DDD systems.[41] Figure 2 depicts the various additive manufacturing techniques used in pharmaceutical sector. To deliver API in various dosage forms, including instant-release tablets, sustained-release tablets, modified-release tablets, immediate-release films, pulsatile-release capsular devices, controlled-release implants, and controlled-release transdermal patches, a 3D printing technique has been used. Drug distribution using the 3D printing technique has been done for both hydrophilic and lipophilic medicines.[42] The solubility and bioavailability characteristics of BCS class II and class IV medications are also improved with the use of 3D printing technology.[43]

FUTURE PERSPECTIVES OF 3D PRINTING

3D printing could be integrated into various healthcare and resource-constrained settings the technology can be used to create medicines that are tailored to the patient's therapeutic needs and requirements (e.g., shape, size, texture, and flavor). 3D printing can be a smarter, faster, and cheaper alternative in drug development and the key for the new generation of printers especially industrial-grade solutions may prove as a substantial aid to handling a vivid range of materials.

CONCLUSION

As 3D printing takes manufacturing near to patients and allows for personalized treatment, it is increasingly popular among patients as a unique method of medication formulation. More effective and safe treatments can be guaranteed thanks to recent technological advancements and greater study in this area. Even though this technology is still in its early stages, it appears to be a ground-breaking tool that provides greater flexibility in drug manufacture and is anticipated to advance DDD systems shortly. We outline the limitless possibilities and uses of 3D printing techniques for the creation of different medicine delivery systems. The capacity of 3D printing to create sophisticated medication delivery systems with numerous pharmaceuticals being administered at various release rates has been shown. Inkjet printing, laser-based systems, SLA, and nozzle-based deposition are some of the most widely used methods in the manufacture of pharmaceuticals. The notion of customized medicine for therapy has gained widespread interest recently since traditional pharmaceutical manufacture is a huge batch procedure and typically does not enable individualized therapy. Many formulations produced using this technique have shown that the specific structure and shape they possess cannot be produced using the conventional manufacturing process. Scientists have spent the last ten years conducting extensive research on a range of 3D printing techniques to improve printers, paving the path for personalized medicine by making it easier to produce innovative and unique dosage forms. This amazing technology makes it convenient to deliver many medications. Consequently, it is simple to create formulations with a variety of medications and release schedules. The pharmaceutical industry has begun to pay greater attention to 3D technology and is working to create distinctive formulations that will allow for the creation of tailored medications by regulating the pace at which the chemicals are released. Technology advancements that are significant and exciting may result in the creation of a single printing system that is capable of producing a variety of release formulas. Several drug releases both rapid and sustained from various polypill partitions have previously been seen in some investigations. Moreover, 3D printing technology has several applications in cutting-edge medicine delivery systems. This also includes multi-layered DDD systems, antibiotic-printed micropatterns, mesoporous bioactive glass scaffolds, and synthetic extracellular matrix microcapsules based on hyaluronan. This approach appears to be a promising method for creating layered materials that are comparable to mucoadhesive films, as was suggested by some studies. Hence, even though they have certain restrictions, this fast prototyping tool is providing the possibility of constructing infinite dose forms that will eventually advance the development of medicinal administration systems to a new level. Yet if the technology is well-established and resources are readily accessible, one might anticipate that 3D printing will become a common production method. The viability of the 3D technique is anticipated to depend on its capacity to provide 3D printing processes that can provide on-demand customized dosages in real-time at dispersed sites. With more formulations on the market, it is anticipated that conventional pharmaceutical manufacturing would soon be replaced by more flexible 3D-printed items. Last but not least, the commercial success of the 3D printing technique will depend on the ability to accurately translate individual dose geometries as per patient requirements while considering the cost.

AUTHORS' CONTRIBUTIONS

S.S. is the main author of the article and he had conceptualized the study and wrote the manuscript. AP.K. has critically reviewed the article and supervised. SK.M. and SK have given the idea for drafting the images and designing the concept, AK was involved in corresponding the article. All the authors have read and approved the final manuscript.

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