INTERNATIONAL JOURNAL OF PHARMACEUTICAL SCIENCES
[ISSN: 0975-4725; CODEN(USA): IJPS00]
Journal Homepage: https://www.ijpsjournal.com

OPEN ACCESS

Review Article

The Review On 3D Printing in Pharmacy

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ARTICLE INFO

Published: 11 Oct 2025
Keywords:
3D printing, History and Evolution, Techniques: Binder jet 3D Printing (BJ3DP), Fused Deposition Modelling (FDM), Semi-solid Extrusion (SSE), Melt Extrusion Deposition (MED), Stereolithography (SLA), Applications, industrial Benefits, Spritam (First USFDA Approve 3D printed Drug), Advantages, Challenges and Limitation, Future Prospects
DOI:
10.5281/zenodo.17320840

ABSTRACT

3D printing, or additive manufacturing, is quickly revolutionizing the realms of pharmaceutical sciences and pharmacy. In contrast to conventional manufacturing relying on the fixed doses and standardized formulations, 3D printing enables drugs to be fabricated layer by layer, tailor to individual patients' requirements. This new freedom of fabrication provides opportunities for revolutionary developments like personalized tablets, polypills of multiple drugs, controlled-release systems, and even drug-loaded implants. Since the early 1980s, a number of printing processes—binder jetting, fused deposition modelling (FDM), semi-solid extrusion (SSE), melt extrusion deposition (MED), and stereolithography (SLA)—have been modified for pharmaceutical as well as industrial applications, each with distinct benefits in drug design and drug delivery, from the beginning till the FDA approval of Spritam, the first 3D-printed drug. The technology has advanced into an adaptive platform and has found applications in drug development, wound care, on-demand manufacturing, and pharmacy education and many more. While the benefits include accuracy, quick prototyping, minimal material waste, and enhanced patient compliance and also problems like regulatory hurdles, expense, scalability, and limited material choices still restrict its full utilization. This review charts the history of 3D printing in pharmacy, outlines its applications and limitations, and considers directions of the future including AI-assisted formulations, bioprinting, and sustainable local manufacture, which collectively suggest a new age of personalized, patient-focused healthcare.

INTRODUCTION

What is 3D printing: -

3D Printing [also called additive manufacturing] is prosses of making three-dimensional solid object from digital file. 3D Printing build object layer by layer using materials such as plastic, resin. Charles

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Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

"Chuck Hull" is credited with investing 3D Printing.

Pharmaceutical 3D Printing

3D Printing is predicted to transform the pharmaceutical industry, the look of medicine development, manufacturing & consumption Potential use extends from pre-clinical drug development and dosage form design right through to production of functionalized implants & regenerative medicine. It is breakthrough technology that enables the production of Personalized drugs. tailored drug dosages & Regulated drug release profiles. It has a broad spectrum of applications, ranging from the manufacturing of complex drug forms to making customized drugs for the specific Patient requirements. Is it possible in the coming times that daily be manufactured with 3D printer on demand, removing the requirement of pharmacies? this query discusses the feasibility, challenges & partial applications. of 3D Printing in Pharmaceutical drug design. Such an idea stemmed out from encountered by High risk. Like of universal issues faced by high risk patient group paediatric & geriatrics. Up to 85% adverse effect is due to these population administered therapies that are not tailored. profiles to individual pharmacokinetics. Splitting tablet is common practice, contributing 25% of tablet administered in Health care. In a practice involves solid dosage form that is divided into two or more sections for treatment. 3D Printing, being an additive manufacturing [AM] process, is the developing technology that transforms computer aided design [CAD] into physical object. Our time is marked by rapid emerging technical development & revolutionary innovation. 3D Printing is quickly become the most cutting-edge technology in pharmaceutics to offer a platform to overcome with deficiency of the 'one size fits all of the approach', As compared to the conventional method. The main 3DP techniques that have been documented in pharmaceutical practices, include fused deposition modelling (FDM), Binder jet 3D printing [BJ-30P], semi solid extrusion (SSE), melt extrusion deposition [MED] and Stereo lithography [SLA). Among these application some key in application elements of new derivates based on seven fundamental AM [Additive manufacturing] in 3D printing technologies. The American Society for testing & Materials has classified AM into the this Seven following categories: Vat Photo polymerization [VPJ. Material jetting (MJ), powder bed fusion (PBF), Binder jetting [BJ), Material Extrusion, Stereolithography (SLJ., Direct energy Deposition [DED], Binder jetting [BJ]. Combinations of key search terms were employed including 3D printing; pharmacy and clinical. In this search included all type of studies and grey literature from 2015 onwards.

History and Evolution of 3D Printing in Pharmacy:-

1] 1980s:- Birth of 3D Printing / Foundation of 3D Printing

i] 1981: Hideo Kodoma from the Nagoya. Municipal Industrial Research Institution in Japan. develops the first rapid prototyping system using UV-curable Photopolymers.

ii] 1986: Charles Hull invents stereolithography printing modal. (SLA) patenting the first 3D printing modal. He developed selective Laser Sintering SLS, a process using a laser to fuse powdered materials layer by layer. SLA was invented in 1984, with patents Filed by alain Lo Mehaute, Olivier de witte, & Jean Claude in France and France & Charles Hull in the USA.

2) 1990s:- Pharmacy Connection:

Early discussion, of 3D Printing for Medical devices (dental implants, Prosthe tics), but not yet for drug delivery. Introduction of selective laser sintering [SLS] and fused deposition modeling [FDA].

i] 1999: Early studies on using 3D printing of drug delivery system began.

3] 2000 - 2010 :- Exploration in dosage of Science from design

Early experimental Studies explored 3D Printing for creating tablets & drug delivery devices.

i] 2002-2005: Research papers describe Printing poly pills [multiple drugs in one tablet]. Researchers tested inkjet printing for Precise drug deposition an tablet .

ii] 2009: First reports of 3D printed oral dosage form i.e. polypills combining multiple drugs in research labs. with controlled release.

4] 2011-2014: Growing interest in Personalized Medicine & Controlled release.

Research accelerated in the Personalized drug delivery, where 3D Printing Could tailor dose, shape, & we release profile.

i]2012: In this FDM 3D printing for immediate & Sustained release tablets.

ii]2013:- Development of multidrug tablet using for chronic disease management first real demonstration of Personalized dosage forms.

5) 2015-2019 : First Clinical-Grade Application/FDA Approval.

i] 2015: Researcher published Successful creation of 3D printed oral tablet with precise drug dosage. Launch of Spritam (Levetiracetam) by Aprecia Pharmaceuticals - The First FDA approved 3D printed drug Technology: Zip Dose, enabling rapid dissolution. Expansion into implants, transdermal patches. Gastro retentive devices & more complex dosage forms.

6) 2020-2022: Advanced Applications, Bioprinting COVID-19 Response.

3D printing used rapid production of medical. devices like ventilator ports & nasal swabs. Advances in 3D bioprinting for tissue models & drug testing platform or tissue engineering. Integration with nanotechnology for targeted drug delivery system. In Personalized oncology treatment using printed implants.

7) 2023-2025 :- Current Trends & Future Directions: 2023-2025

4D Printing: Explored for controlled, targeted drug release & time-specific drug release. Multi material Printing combines immediate 5 sustained release layers in one tablet. On-demand Hospital Pharmacies evolving for Hospital or pharmacy based on demand drug printing. Research into AI: Personalized dose based on genetic profile & disease state Research into AI-driven. Pharmacogenomics - guided personalized drug. Sustainability using biodegradable polymers / materials in Printing. Pharmaceutical printing.

3D Printing Techniques in Pharmaceutical Manufacturing :-

1} Binder jet 3D Printing :-

In BJ-3DP, a thin layer of Powdered of pharmaceutical excipient spread on a build Platform. A liquid binder is precisely deposited by an inkjet printhead. The binds droplets the powder particle of together is selected regions, the process repeats layer by layer until the final dosage form is created. After printing, drying or curing is done to remove solvents & improve mechanical strength.

Working :

1) Powder layer Deposition is the thin layer of Powdered material is spread evenly the build platform using a roller or blade, the powder must have good flowability and particle size distribution for smooth layering.

2) Binder Deposition is the process inkjet printhead select selectively deposits tiny droplets of liquid bind, the binder wets & partially powder particle, cause them to stick together.

3) Layer by layer Building is after deposition the platform lowers slightly. A Fresh powder layer is spread top & the process repeats. It's continues until the full 3D Printed structure is form.

4) Drying is the printed structure contains solvent from the binder, which is removed by drying.

5) After additional steps like coating or surface modification may be done.

2) Fused Deposition Modelling [FDM] :-

FOM is on 3D Printing method where drug-loaded thermoplastic filaments is heated, softened through a nozzle, the printer deposits layer by layer to build a solid dosage form.

Working :

1) Preparation of Drug Loaded Filaments in this process API & excipients are mixed & this mixture is extruded into a filament using hot-melt extrusion. The drag molecules can be molecularly dispersed in the polymers.

2) Feeding into Printer in this filament is fed into heated nozzle FDM 3D printer this nozzle temperature set above the polymer's glass transition melting temperature.

3) Extrusion & Deposition in this the molten drug polymers mixture is extruded through and the nozzle, the printer moves according to the CAD design, deposing material layer by layer.

4) After is Solidification ac are in this the layer is cools is solidified quickly, subsequent layers fuse together to form the final 3D Printed structure.

3) Semi- Solid Extrusion [SSE] :-

SSE is use semi- solid pastes, gels instead of Solid filaments. the semi-solid material is pushed through a syringe like nozzle using the pressure. The extruded material [pushed material] is deposited layer by layer to form the desired 3d structure, which then solidified.

Working :

1) Preparation of Semi-solid Material the drug is mixed with Excipients, to form gel/ Paste, excipient may be include hydrogel polymer, lipids any semi-solid carriers.

2) The semi-solid formulation a re-filled into syringe or cartridge, which is attached to the printer head.

3) Extrusion is the process-controlled pressure pushes the semi-solid material through the nozzle, this printer follow design digit to deposit material in layer by layer.

4) The printed Structure sets via solvent evaporation, cooling or chemical crosslink I become solidified.

4) Melt Extrusion Deposition [MED] :-

In MED, drug loaded feedstock is directly fed into the printer, the material is melted in the printhead. The molten is extruded through a nozzle deposited layer hy layer to form the dosage form.

Working :-

1) Material Preparation is first step in this API & Excipients blended into powder or granules.

2) Feeding into Printer, the drug-excipient blend in fed directly into the extrusion chamber, in this no pre-formed filament is required.

3) Material is heated into the printhead to above its softening/ melting temperature, the drug may become molecularly dispersed in the polymer matrix.

4) Deposition of the molten mixture is extruded through a nozzle, deposition follow the CAD design to build the dosage form layers.

5) The Solidification is done, the deposited layers cool rapidly, fusing together to form the Structure dosage Structure.

5) Stereolithography [SLA):-

It is a light-based 3D Printing technology in this it uses liquid resin photopolymer resin that solidifies when exposed to UV light or digital light projection.

Working:

1) Preparation of Photopolymer Resin is made photo polymerizable excipients, the drug either dissolved, suspended or dispersed of in to the resin.

2) A UV laser or projector selectively irradiates region of the resin according to the CAD Model, the resin solidifies only where light is applied.

3) After one layer is Cured the build platform moves [up & down). A fresh layer of over the cured layer this Process continuous until the full 3D structure is build.

4) Post Processing in this Printed parts are rinsed to remove uncured resin, further UV curing may be applied to improve the strength.

Application of 3d printing in pharmacy: -

1) Personalized Medicine: -

One of the most promising uses of 3D Printing in the pharmaceutical field development is the of Personalized medicine. Unlike traditional manufacturing, where drug produced in fixed doses and limited forms, 3D Printing makes it possible to prepare that are customized for each patient that individual needs. For example; many specific many patients require very specific dose which are not available in market. Children, elderly people, and Patients with liver or kidney problem often need smaller or adjusted dose with 3D printing, the exact amount of drug can be printed into tablet, making treatment more accurate and reducing the risk of side effect. Another exciting application is the creation of "polypills". Patients with chronic condition such as diabetes, hypertension, or heart disease usually take several pills every day. This can be tiring & often leads poor compliance it allows multi drug be combined single tablet in the single with each layer programmed to release the drug at different times or in different parts of the body. 3D Printing, also gives flexibility in the shape and internal structure of designing tablet. Another benefit of 3D printing, is on-demand drug manufacturing, instead of producing large scale in factories, Hospitals or pharmacies large scale can print patient specific medicines on the spot. 3D printing opens doors for paediatric and geriatric formulation with Customized size, colour, flavour, and release profile .It can even be combined with bioprinting technique to develop personalized implants or drug-loaded scaffolds for regenerative medicine.

2)Complex Dosage forms :-

One of the most exciting application of 3D Printing in the pharmaceutical field is its ability of drug design & manufacture-complex dosage forms that are otherwise difficult to achieve by the traditional techniques. Conventional tablet Compression or capsule filling methods that have limitations when it comes producing personalized shapes, muti-drug combination, or controlled release layer but 3D printing overcomes these challengers by allowing precise its Placement of layer by layer, make it possible to create highly sophisticated drug delivery system. For example, complex dosage forms such as multilayer tablet, polypills & drug loaded scaffolds can be manufacturer with great accuracy. This not only improve patient compliance by reducing pill burden but also enables tailored therapy for condition that require combination treatment, such as cardiovascular disease, diabetes, or Cancer. The development of modified-release formulation, 3D printing makes it possible to print tablets with intricate internal structure, like channels or porous material which control the drug dissolves & releases time. This dosage forms can be delayed pulsatile release profile & sustained. In addition, research for expanding towards implantable dosage form & personalized drug eluting devices, where this technology. provide precise control over size, shape, and drug distribution. These drug delivery, especially in oncology & chronic disease management.

3] On-demand Drug Production :-

One of the most promising applications of 3D printing in the pharmaceuticals is the possible of producing medicines on demand. Traditional drug manufacturing, relies on large scale production lines, centralized facilities, & bulk distribution While this System ensure often struggles mass availability it can issues such as long often struggle with issue such as long supply chain, storage limitation, drug shortages and lack of personalized formulation. shortages, & lack of personalized formulation 3D printing offers the ways to overcome these barriers by enabling raid localized patient specific drug production.

There are some key aspects;

1) Rapid manufacturing

2) Customization of Dosage

3) Decentralized Production

4) Reduction of Waste

5) Improved Drug Availability in Rare Disease

6) Potential in Space & Military medicine

4] Improved Drug Delivery System :-

The pharmaceutical industry is continually seeking innovation approaches to enhance drug, safety, efficacy, & Patient compliance. One of the most promising technologies in recent years is 3D Printing also known as additive manufacturing which allows precise fabrication of drag products with complex structure & Personalized characteristics. Its application in improving drug delivery system is transforming "traditional pharmaceutical manufacturing". The world of pharmaceuticals is experiencing a quiet revolution, & at the heart of it lies 3D Printing a technology better known for making toys, prototype or even in house, but now reshaping how we think about medicine, imagine a future where doctor' doesn't just prescribe a pill but design it specifically for your body, metabolism & lifestyle.

5)Drug Development :-

3D Printing, is also known as additive know additive manufacturing, is emerging as a

transformative technology in drug development. Unlike traditional manufacturing of drug, it allows precise fabrication of customized dosage from enabling personalized medicine tailored individual according to patient need. It also supports the creation of complex a drug dosage formulation that are hard to produce conventionally, such as multi-drug tablet or controlled -release system. The key advantage is rapid prototyping, which accelerates formulation testing.

6)Wound Care :-

3D printing has opened new horizons in the development of advanced wound care system, offering precise, customized effective solution that traditional method often cannot achieve in pharmaceutical manufacturing, it allows the creation of wound dressing, scaffold & patches with properties for enhance healing.

(i) Customized wound Dressing :-

The 3D Printing enables the fabrication personalized wound dressing that conform to the precisely shape and size of a patient's wound, it can ensure better coverage, reduces the risk of interaction & enhances the patient contest.

(ii) Drug-loaded Wound system :-

A major advantage of 3D printing is the ability in incorporate threptic agent directly into wound care products.

(iii) Complex Scaffold Design :-

3D Printing allows the creation of biodegradable scaffolds with precise internal architecture that promote tissue growth and regeneration. This can also guide cell growth, enhance angiogenesis and increase the acceleration wound closure.

(iv) Rapid Prototyping & innovation :-

Researcher can quickly design and print multiple version of wound care system to wound system to test properties such as drug releases mechanical strength allow for continuous innovation in wound care solution.

v) Smart wound Care devices :-

It Can printed smart dressing that can monitor wound such as pH and infection markers and release drugs in response to changes.

7] Education in Pharmacy :-

3D printing is not only revolutionizing pharmaceutical manufacturing but it is coming into powerful tool in the Pharmacy education. In academic setting, it can provide student with practical & interactive ways to a practical understand a complex topic such as dosage form design, & Drug delivery system manufacturing processes, But by the way of using 3D printers, pharmacy students can create models of tablet capsule anatomical structure, realistic even implants and even which enhance their grasp of formulation science & Patient-centred drug design. This hands-on approach bridges the gaps between the practical of theory make the learning experience more engaging & effective. Students can experiment with printed dosage form different sizes, shapes profiles, which understanding how it influences pharmacokinetics and pharmacodynamic. It is can also beyond only dosage forms, it prints also used to create simulation models for training, i.e. artificial organ or student tissues, which can help the learn about targeted drug delivery.

Benefits of 3D printing in the pharmaceutical industry:-

1) Drug Development & Research: Speeds up prototype drug formulation quick testing of

Dosage forms. Reduces R&D costs by minimizing trial & error in formulations.

2) Enhanced Precision & Accuracy: 3D printing allow for highly accurate &precise control over drug dosage & release profiles.

3) Flexible Manufacturing: Shifts form mass production to on-demand, small batch production. Allows customized medicines without changing the entire production line.

4)Cost Efficiency: Reduce manufacturing costs by lowering materials waste, storage and transportation need, Avoids overproduction & Expiry related losses.

5) Reduced Material Wastage: Compared to traditional manufacturing, 3D printing can minimize material waste, especially in personalized medicine application.

6)Supply Chain Transformation: Medicine can be printed closer to patient [i.e. hospital, pharmacy disaster zone, space], less Reliance on centralized factories and long distribution chains.

7)Regulatory & Quality Advantage: 3D printing ensure precise dosing & consistent product quality. Easier to adapt to good manufacturing practices [GMP]with automation.

8) Expanding Market Opportunities: Opens doors to orphan drugs [rare disease] where mass production is not profitable, Custom batches for clinical trials at lower cost.

Ex.

1] Speritam [Levitiracetam]- The First 3D printed medicine.

General Information:

Drug name -Levitiracetam

Brand -Spritam

Company -Aprecia pharmaceuticals

Approval -2015 by the USFDA

Use - Treatment of epilepsy/seizures

Why is it special: 1st FDA - approved 3D printed tablet. Manufacturing with zipdose technology ---> builds the tablet layer by layer. Create a highly porous structure ---> dissolves instantly in just a sip of water. Patient - friendly: Easy to swallow even at high doses [up to 1000mg]. Personalized dosing possible. Common adverse effect: In clinical trials, the most common adverse effect seen in people who takes SPRITAM includes sleepiness, weakness, and infection. In addition to those previously listed, the most common side effects seen in children who take SPRTAM includes tiredness, acting aggressive, nasal congestion, decreased appetite, and irritability.

2]Triastek's 3D Capsule:

Triastek's 3D printed drug for ulcerative colitis is named T21. Manufactured using Triastek's proprietary Melt Extrusion Deposition [MED] 3D printing technology. It is an oral medication The original drug is a JAK inhibitor called tofacitinib Janus kinase inhibitors It is class of inhibitor s TAT signalling pathway, a key pathway in immune cell function inflammation.

Original Drug : Tofacitinib

Therapeutic Area : Ulcerative colitis

Status: In Frist in human [FIH] studies with investigation new drug [IND].

Advantage of 3D Printing in Pharmacy :–

1] Personalized Medicine: Customizes drug dosage form, size & shape for individual Patient.

2) Complex dosage forms: Produces layered tablets multilayer drug combination and controlled release system.

3) Rapid Prototyping: Accurate drug development and testing of new formulation.

4) On-demand Manufacturing: Enable local hospitals production.

5) Improved Patient Compliance: Creates, formulate, chewable, flavoured or visually appealing dosage forms.

6) Reduced material wastage: Uses only required APIs & excipient.

7) Advanced drug delivery: Provides controlled targets or sustained drug release.

8) Small batch Production: Use in mostly rare disorders.

9) Education & training: Enhances Pharmacy learning.

10) Customization of implants: Produce patient-specific stents, implants & patches.

11) Eco friendly approach: Minimize manufacturing and environmental implant.

12) Lower Storage costs: On-demand manufacturing reduces the need for long-term storage.

13) Reduced Supply Chain burden: Drug can be produced closer to Patients; Delay not possible.

14) Better drug Stability: Some printing methods stabilize heat or Sensitive drugs.

15) Noval drug Shapes: Creates innovative designs.

16) Paediatric & geriatric friendly forms: Maks easy to swallow or chewable options.

17) Combination therapy: Allows multiple drugs in a single dosage unit.

18) Improved Patient Safety: Reduced dosing errors by creating accurate, patient-specific forms.

Challenges & Limitations of 3D Printing in Pharmacy:-

1) Regulatory hurdles: less, lack of clear guidelines from agencies like FDA/EMB for approval of 3D Printing.

2) Quality control issues: Ensuring uniformity, dose a porosity of mechanical strength remains difficult.

3) Scalability Concerns: like conventional manufacturing large-scale mass production is still less efficient.

4) High initial cost: Equipment, software, and specialized material require significant investment.

5) Limited materials: Only certain polymers. excipients, & drug compounds compatible with printing.

6) Time-consuming process: Printing each tablet individually can be slower compared to batch production.

7) Stability challenges: Heat & mechanical stress during printing may degrade sensitive drugs.

8) Training Requirements: Pharmacists of technicians need specialized knowledge to operate printers.

9) Post-processing needs: Many printed products requins additional steps like drying.

10) Limited drug load capacity: Some method struggle, with incorporating high doses.

11) Mechanical strength limitations: Some printed are fragile or crumble tablets. easily driving heading.

12) Energy consumption: Continuous operations 3D Printers can be resource – intensive.

13) Drug-excipient interaction: Not all excipients work well under 3D printing condition.

14) Printer maintenances: Frequent calibration & upkeep needed for accurate production.

15) Not suitable for all drug types: large molecules like biologics are difficult to print.

Future Prospects of 3D Printing in pharmacy:-

With 3d printing is already reshaped pharmaceutical manufacturing by enabling customization, fast prototyping and innovation drug delivery system. The future, promises a much more broader impact, moving beyond conventional application towards highly intelligent patient centred and sustainable.

1} Hyper-Personalized Therapy: Genetic-based formulations in future 3D printed drug could be tailored not only to weight, age, sex but also to individual genetic-codes than enhancing treatment efficacy. Patient-centre design medication could be customized in shape, colour, Flavour, odour or air dosage forms to improved adherence e specially in Paediatric and geriatric people.

2) Integration with Smart Healthcare: IoT-Enabled Medications pills could incorporate sensors or chips to monitor pharmacokinetics, pharmacodynamic, adverse effect, adherence or therapeutic action. Remote Printing fur Telemedicines Patients in remote locations could receive it's personalized medication printed locally free by clinicians digital prescription sent. AI-Driven Formulation design could be predict optimal drug combination and release profiles, which printers would then manufacture on demand.

3) Novel Drug Delivery Platforms: Implatable therapeutics could enable biodegradable implants that release drug over weeks months. Future printing may combine nanotechnology and additive manufacturing to directly drug to disordered cell deliver drugs tissue. Patches microneedles, & transdermal system could be printed to match patient comfort for controlled, painless drug delivery.

4) Revolutionizing Clinical trials of Drug Development :- 3D Printing new can accelerate the development of new drug by producing small batches quickly and easy for early-stage testing. Bio printed organs or tissues could replace traditional models increasing accuracy and reduce the animal & for testing.

5) Sustainable and localized Pharmaceutical Manufacturing :- Additive manufacturing done only material where needed, minimizing production wastage. In Hospitals, pharmacies or in even the house may print medication on site, reducing storage, other needs and supply chain problem.

6) Future Regulatory & Quality Framework :- Advanced AI, sensors printed dose with strict could ensure every quality standards. Standardized protocols could enable widespread adoption of Personalized medication while it ensure the efficacy and Safety.

CONCLUSION: -

3D printing has transformed from being an experimental technology into a true game-changer in pharmacy and pharmaceutical industry. Its power lies in providing what the conventional manufacturing cannot: real personalization, intricate dosage forms, and quick adjustment to patient needs. It can alleviate patient with polypills' tablet burden, facilitate easy swallowing of drugs for children or elderly patient, and its novel release mechanisms enhancing both safety and patient compliance. On the other end of oral drug delivery systems, its uses go as far as implants, wound management, and even educational instruments in teaching pharmacy students. Nevertheless, the journey to the routine clinical application is not without challenges. But high prices, regulatory unknowns, and technical constraints are still a concern to the user. While we have roadblocks, but there is high opportunity in future. With the emerging science of artificial intelligence, bioprinting, and intelligent healthcare technologies, 3D printing became a foundation of precision medicine, but to make this vision come true, collaboration among researchers, industry, regulators, and healthcare providers will be required. Basically, 3D printing is more than a novel method of manufacturing—it is an omen pointing toward truly personalized, affordable, and revolutionary pharmaceutical treatment.

ACKNOWLEDGEMENT:

The authors sincerely express their gratitude to Dr. Nilesh S. Mhaske for their valuable guidance, encouragement, and continuous support throughout the preparation of this review article of 3D Printing in Pharmacy. His insightful suggestions and expert supervision have been instrumental in shaping the quality and depth of this work. The author also extend their appreciation to their institution and colleagues for providing the necessary resources and academic environment that facilitated this study.

Conflict of interest :

The author declared no conflict of interest with respect to the authorship and publication of this article.

Availability of data and material :

All the data used in our article are available from publicly accessible sources such as PubMed, Elsevier, Wikipedia, etc.

Funding :

The authors received no financial support for the authorship and for publication of this article.

REFERENCES

1. Tobias Auel, Aaron Felix Mentrup, Lee Roy Oldfield, Anne Swidlitz: 3D printing of pharmaceutical dosage forms: Recent advances and applications, 217 (2025) 115504.
2. Jessica T Y Cheng, Edwin C K Tan, and Lifeng Kang: Pharmacy 3D printing, IOP Publishing, Biofabrication 17 (2025) 012002.
3. Maria C Simon, Konstantinous Laios, Ioannis Nikolakakis and Theodore G Papaioannou: Three-Dimensional Printing Technology in Drug Design and Development: Feasibility, Challenges, and Potential Application. J. Pers. Med. 2024, 14, 1080.
4. Nicola Paccione, Victor Guarnizo-Herrero, Murugan Ramalingam, Eider Larrarte, Jose Luis Pedraz: Application of 3D printing on design and development of Pharmaceutical oral dosage form 373 (2024) 463-480.
5. Jurga Bernatoniene, Jolita Stabrauskiene, Jurga Andreja Kazlauskaite, Urte Bernatonyte, and Dalia Marija Kopustinskiene: The Future of Medicine: How #d Printing Is Transforming

Pharmaceuticals. Pharmaceutical 2025 , 17 , 390. https://doi.org/10.3390/ pharmaceutics17030390.

6. Abdul W Basit and Sarah J Trenfield, Corresponding author Abdul W Basit: 3D Printing of pharmaceuticals and the role of pharmacy
7. Ranjitsinh Pawar and Atmaram Pawar: 3D printing of pharmaceuticals: approach from bench scale to commercial development: 26 November 2022.
8. Vanshika Sautha1, Mansi Butola1*, Meenu Chaudhary3, Praveen Kumar4, Vikash Jakhmola2, Siddhant Dhyani1 and Arif Nur Muhammad Ansori5: Overview of 3d Printing Technology with Pharmaceutical Applications, Challenges and Future Aspects: 10 February 2025.
9. Pavan Kalyan BG, Sonal Mehrotra, Shirleen Miriam Marques, Lalit Kumar, Ruchi Verma: 3D printing in personalized medicines: A focus on applications of the technology: Volume 35 June 2023, 105875.
10. Wang S, Chen X, Han X, Hong X, Li X, Zhang H, Li M, Wang Z and Zheng A 2023 A review of 3D printing technology in pharmaceutics: technology and Applications, now and future Pharmaceutics 15 416.
11. Beer N, Hegger I, Kaae S, De Bruin M L, Genina N, Alves T L, Hoebert J and Kälvemark Sporrong S 2021Scenarios for 3D printing of personalized medicines—A case study Explor. Res. Clin. Soc. Pharm. 4 100073.
12. Cui M, Pan H, Su Y, Fang D, Qiao S, Ding P and Pan W 2021 Opportunities and challenges of three-dimensional printing technology in pharmaceutical formulation development Acta Pharm. Sin. B 11 2488–504.
13. Varghese R, Sood P, Salvi S, Karsiya J and Kumar D 2022 3D printing in the pharmaceutical sector: advances and evidences Sens. Int. 3 100177.
14. Yang H S and Kim D W 2023 Fabrication of gastro-floating famotidine tablets: hydroxypropyl methylcellulose-based semisolid extrusion 3D printing Pharmaceutics 15 316.
15. Cheng Y, Qin H, Acevedo N C, Jiang X and Shi X 2020 3D printing of extended-release tablets of theophylline using hydroxypropyl methylcellulose (HPMC) hydrogels Int. J. Pharm. 591 119983.
16. Chen G, Xu Y, Chi Lip Kwok P and Kang L 2020 Pharmaceutical applications of 3D printing Addit. Manuf. 34 101209.
17. Cailleaux S, Sanchez-Ballester N M, Gueche Y A, Bataille B and Soulairol I 2021 Fused deposition modeling (FDM), the new asset for the production of tailored medicines J. Control. Release 330 821–41.
18. Anwar-Fadzil A F B, Yuan Y, Wang L, Kochhar J S, Kachouie N N and Kang L 2022 Recent progress in three-dimensionally-printed dosage forms from a pharmacist perspective J. Pharm. Pharmacol. 74 1367–90.
19. Mohammed A A, Algahtani M S, Ahmad M Z, Ahmad J and Kotta S 2021 3D printing in medicine: technology overview and drug delivery applications Ann. Med. 4 100037.
20. Mostafaei A, Elliott A M, Barnes J E, Li F, Tan W, Cramer C L, Nandwana P and Chmielus M 2021 Binder jet 3D printing—Process parameters, materials, properties, modeling, and challenges Prog. Mater. Sci. 119 100707.
21. Yu D G, Zhu L-M, Branford-White C J and Yang X L 2008 Three-dimensional printing in pharmaceutics: promises and problems J. Pharm. Sci. 97 3666–90.
22. Kanishka K and Acherjee B 2023 Revolutionizing manufacturing: a comprehensive overview of additive manufacturing processes, materials, developments, and challenges J. Manuf. Process. 107 574–619.

23. Altıparmak S C, Yardley V A, Shi Z and Lin J 2022 Extrusion-based additive manufacturing technologies: state of the art and future perspectives J. Manuf. Process. 83 607–36.
24. Seoane-Viano I, Januskaite P, Alvarez-Lorenzo C, Basit A W ˜and Goyanes A 2021 Semi-solid extrusion 3D printing in drug delivery and biomedicine: personalised solutions for healthcare challenges J. Control. Release 332 367–89.
25. Ngo T D, Kashani A, Imbalzano G, Nguyen K T Q and Hui D 2018 Additive manufacturing (3D printing): a review of materials, methods, applications and challenges Compos. Eng. 143 172–96.
26. Siyawamwaya M, du Toit L C, Kumar P, Choonara Y E, Kondiah P P P D and Pillay V 2019 3D printed, controlled release, tritherapeutic tablet matrix for advanced anti-HIV-1 drug delivery Eur. J. Pharm. Biopharm. 138 99–110.
27. Jayanth N, Senthil P and Mallikarjuna B 2022 Experimental investigation on the application of FDM 3D printed conductive ABS-CB composite in EMI shielding Radiat. Phys. Chem. 198 110263.
28. Shojaie F, Ferrero C and Caraballo I 2023 Development of3D-printed bicompartmental devices by dual-nozzle fused deposition modeling (FDM) for colon-specific drug delivery Pharmaceutics 15 2362.
29. Gorkem Buyukgoz G, Soffer D, Defendre J, Pizzano G M and Davé R N 2020 Exploring tablet design options for tailoring drug release and dose via fused deposition modeling (FDM) 3D printing Int. J. Pharm. 591 119987.
30. Patel N G and Serajuddin A T M 2021 Development of FDM 3D-printed tablets with rapid drug release, high drug-polymer miscibility and reduced printing temperature by applying the acid-base supersolubilization (ABS) principle Int. J. Pharm. 600 120524.
31. Algahtani M S 2021 Assessment of pharmacist's knowledge and perception toward 3D printing technology as a dispensing method for personalized medicine and the readiness for implementation Pharmacy 9 68.
32. Goyanes, A.; Chang, H.; Sedough, D.; Hatton, G.B.; Wang, J.; Buanz, A.; Gaisford, S.; Basit, A.W. Fabrication of controlled-release budesonide tablets via desktop (FDM) 3D printing. Int. J. Pharm. 2015, 496, 414–420. [CrossRef] [PubMed].
33. Su, A.; Al'Aref, S.J. History of 3D printing. In Elsevier eBooks; Elsevier: Amsterdam, The Netherlands, 2018; pp. 1–10. [CrossRef] 9. Khaled, S.A.; Burley, J.C.; Alexander, M.R.; Yang, J.; Roberts, C.J. 3D printing of five-in-one dose combination polypill with defined immediate and sustained release profiles. J. Control. Release 2015, 217, 308–314. [CrossRef].
34. Vo, A.Q.; Zhang, J.; Nyavanandi, D.; Bandari, S.; Repka, M.A. Hot melt extrusion paired fused deposition modeling 3D printing to develop hydroxypropyl cellulose based floating tablets of cinnarizine. Carbohydr. Polym. 2020, 246, 116519. [CrossRef].
35. Karakurt, I.; Aydo˘gdu, A.; Çıkrıkcı, S.; Orozco, J.; Lin, L. Stereolithography (SLA) 3D printing of ascorbic acid loaded hydrogels: A controlled release study. Int. J. Pharm. 2020, 584, 119428. [CrossRef].

HOW TO CITE: Dr. Nilesh Mhaske*, Prem Dalvi, The Review On 3D Printing in Pharmacy, Int. J. of Pharm. Sci., 2025, Vol 3, Issue 10, 975-987 https://doi.org/10.5281/zenodo.17320840