INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD)
© 2026 IJNRD | Volume 11, Issue 5, May 2026 | ISSN: 2456-4184 | IJNRD.ORG

3D PRINTING USED IN PERSONALIZED MEDICINES

Satyajit Sahoo[1] , Aftab Mansuri*, Devendra Vaghela[1],Mukesh Patel[1], DB Meshram[1]
Pioneer Pharmacy College, Ajwa-Nimeta Road, Vadodara, Gujarat, India -390019

Abstract:
The advent of 3D printing is proving to be a game-changer in personalized medicine as it can help develop tailor-made drug delivery systems and medical devices for patients. Traditional drugs have limitations as they do not cater to the needs of each patient based on his/her age, genetic makeup, disease state, and therapeutic responses. The use of 3D printing has the potential to overcome this drawback as it can help deliver exact doses of medicine according to shape, size, drug release and combination therapy. Some of the techniques that can be employed to print drugs include fused deposition modeling (FDM), stereolithography (SLA), selective laser sintering (SLS), inkjet printing, and semi-solid extrusion. Some applications of this technology in medicine include customized pills, implants, transdermal systems, and multi-drug combination therapies. Along with technological advancement in 3D printing, progress in artificial intelligence, computer-aided design, and 4D printing is making the concept of personalized medicine even more feasible. Nevertheless, certain concerns regarding regulatory approval, printing accuracy, material usage, cost of printing, and scalability limit the application of this technique at a larger scale.

Keywords: 3D Printing, Personalized Drug Delivery, Customized Pharmaceuticals, Additive Manufacturing, Precision Medicine, Drug Release Systems, Biomedical Applications

INTRODUCTION:

Three-dimensional (3D) printing (also known as additive manufacturing) is a layer-by-layer fabrication technology that converts digital designs from computer-aided design (CAD) software into solid dosage forms. In pharmaceutical field it has been used for the preparation of several drug delivery systems such as polypills, controlled release tablets, Oro dispersible films, transdermal patches, microneedles and gastro-floating tablets. [1,2,3] The roots of three-dimensional (3D) printing go back to stereolithography, invented by Charles W. Hull and commercialised in 1986.[4] The pharmaceutical industry has focused a lot on 3D printing as experts see it as a way to dramatically improve the production of dosage forms. [5,6] 3D printing has revolutionised sectors such as manufacturing, engineering and medicine over the years. In health care, its uses include the production of patient specific medical models and drug delivery systems and tissue engineering with vascular, neural and skeletal structures. Critically, 3D printing allows for the manufacture of customised single- or multi-drug dosage forms, supporting precision medicine. [7,8]

Personalized medicine:

The Horizon 2020 Advisory Group describes personalised medicine as “a medical model that employs the characterisation of the phenotypes and genotypes of individuals, such as lifestyle data, medical imaging or molecular profiling, to tailor the right therapeutic strategy for the right person at the right time, and/or to determine the predisposition to disease and/or to deliver timely and targeted prevention” [9,10]. The term personalised medicine is also not the only term used to describe the same concept, as other terms are used, such as individualised medicine, precision medicine, stratified medicine, pharmacogenomics, genomic medicine, and P4 medicines, including personalised, predictive, preventive, and participatory [11]. Personalised medicine (PM) includes patient-specific tissue regeneration, implanted therapeutic devices and tailored doses of medication. This breakthrough has resulted in 3D bioprinting, the construction of living cells and biomaterials into functional structures, becoming a vital tool in the development of regenerative solutions that improve personalised medication treatment. [12,13]

Need of 3D Printing in Personalized Medicine:

1. Requirement for Individualised Drug Dose:

The dose needed by different patients varies depending on factors like:

- Age:
- Mass of the body
- Genetic profile
- Degree of disease
- Function of organ [14]

Standard dosage forms deliver fixed doses which may lead to underdosing or overdosing in some patients. 3D printing allows precise customisation of drug dose to individual therapeutic needs [15].
This is especially useful for:

- Children
- Elderly patients
- Those with cancer
- Patients with renal or hepatic dysfunction [15]

2. **Management of Polypharmacy:**

Patients with diseases usually have to take a lot of medications all at the same time. When patients have to take a lot of pills it can be hard for them to remember to take Polypharmacy medications. Taking a lot of Polypharmacy medications can also increase the chance of making mistakes with Polypharmacy medications [16].
3D printing makes it possible to make special pills called polypills. These polypills are special because they have Polypharmacy medications, in one pill and each Polypharmacy medication works at a different time [17].
The good things about Polypills are:

- You have to take pills
- People are more likely to take their medication
- It is easier to follow the treatment
- There are mistakes with medication [17]

A famous example is the five-, in-one polypill that was made using 3D printing technology [18].

3. Customization of Drug Release Profiles:

diseases need different drug release patterns like:

- Immediate release
- Sustained release
- Delayed release
- Pulsatile release [19]

3D printing lets us have precise control over things like:

- The shape of the tablet
- How dense the inside of the tablet is
- The surface area of the tablet
- What the inside of the tablet looks like

These things directly affect how the drug is released.[20]
Customization of Drug Release Profiles is important because Drug Release Profiles can be different. Thus, we can make medicines with Drug Release Profiles that are specific, to each patient using 3D printing and other similar technologies.[20]

4. Improvement in Patient Compliance:

A lot of people have trouble swallowing pills, especially kids and older people.[21]
3D printing makes it possible to make some kinds of medicine like:

- Tablets that you can chew
- Tablets that dissolve in your mouth
- Gummies
- Medicine that comes in different Flavors
- Medicine that comes in shapes and colours that you like [22]

These kinds of medicine are easier for people to take so they are more likely to take their medicine and get better [22].

5. Need for Personalized Therapy in Chronic Diseases:

Diseases that people have for a time such, as:

- Cancer
- Diabetes
- High blood pressure
- Heart problems
- Nerve diseases

need treatment that is tailored to each person for a very long time.[23]

3D printing makes it possible to create medicines that are made just for a person's specific disease, how well they respond to treatment and the unique signs of their body.[24]

In the field of cancer treatment medicines that are made just for one person can make treatment work better. Reduce bad side effects.[24]

6. Advancement of Pharmacogenomics:

Pharmacogenomics looks at how genetic variations affect how people respond to drugs. Genetic differences can really affect how the body handles drugs. For example, they can change:

- how the body breaks down a drug
- how the body moves a drug around
- how toxic a drug is
- how a drug works [25]

Pharmacogenomics studies this. 3D printing helps with this kind of therapy by letting people make doses of drugs that are tailored to a person's genetic information. This is a help to pharmacogenomics. 3D printing work together to make drugs that are just right, for each person.[26]

7. Need for Complex Dosage Forms:

The usual ways we make medicine do not work well for making systems that deliver drugs to our bodies. That is where 3D printing comes in. It helps us make things like:

- Multi-layer tablets
- compartment systems
- Floating tablets
- Gastro-retentive systems
- Porous structures [27]

These new kinds of drug delivery systems, like multi-layer tablets and multi-compartment systems really help our bodies use the medicine better. They also work better to make us feel better and are easier for patients to use.[27]

8. On-Demand Manufacturing of Medicines:

Traditional medicine making needs factories and lots of storage space. With 3D printing we can make medicines as needed right at hospitals, pharmacies or healthcare centres.

Benefits of this method include:

- waste from making medicines
- Quick production of drugs
- Improved management of medicine stock
- Faster access to medicines [28]

This way of making medicines is really helpful during emergencies and for rare diseases that need special treatment, for each person.[29]

9. Reduction in Adverse Drug Reactions:

Adverse drug reactions are a problem for people who get medical care. When people take the amount of medicine or take the wrong medicines together it can be very bad for them [30].
3D printing is helpful in reducing drug reactions by doing a few things:

- Giving people the right amount of medicine that is just, for them
- Making sure the medicine works the way it should
- Not giving people more medicine than they need
- Making sure the medicine does what it is supposed to do [30]

10. Applications in Tissue Engineering and Regenerative Medicine:

3D printing is used in a lot of things. Here are some examples:

- Tissue engineering
- Organ bioprinting
- Bone implants
- Cartilage regeneration
- Personalized prosthetics [31]

The thing about 3D printing technologies, like bioprinting is that they let us make custom tissues and scaffolds that fit each patient's body. This is really good for therapy outcomes [31]. 3D printing or bioprinting is a help, in making therapy better for people.

11. Economic and Healthcare Benefits:

Although the initial costs of printing equipment are high 3D printing can help reduce long-term healthcare costs in several ways:

- It can make treatments work better with 3D printing
- It can lower the number of hospitals stays with 3D printing
- It can help prevent mistakes with medicines using 3D printing
- It can help patients follow their treatment plans better with 3D printing [32]

Personalized therapy, with 3D printing also means that doctors do not have to try as many different treatments and it makes healthcare work more efficiently with 3D printing.[32]

Types of 3D Printing Technologies Used in Personalized Medicine:

Personalized medicine is a way of treating patients. It is customized based on a patient's genes, physical condition, disease, age, weight and how they respond to treatment.Most medicine manufacturing uses an approach that may not work best for every patient.So, there is a growing need for technologies that can make medicines tailored to patients with exact dosing and customized release. [33,34] Three-dimensional printing, also called manufacturing is a game-changing technology in personalized medicine. This is because it allows the creation of customized medicine forms, from computer designs.[35]The technology lets us have precise control over the shape of tablets how much medicine they have how porous they are and how the medicine is released. We can even put than one type of medicine in a single tablet. [36] This is a deal.The first big success in making medicines with printing happened after the FDA said it was okay to use a 3D printed drug called Spritam, which is used to treat epilepsy.[37] This medicine is made using something called Zip Dose technology.Since then, people have been looking into lots of 3D printing methods to make personalized medicines. These methods include Fused Deposition Modelling, Stereolithography, Selective Laser Sintering, Inkjet Printing and Semi-Solid Extrusion. The technology enables control over tablet geometry and the release profile of 3D printed medicines, like Spritam.[38]
The main goals of 3D printing, in medicine are to do things like:

- Make special doses just for one person
- Create systems that release the amount of medicine at the right time
- Make pills that have many drugs in them
- Help patients take their medicine as they should
- Make medicine when it is needed
- Lower the effects of medicine and mistakes when giving medicine [39,40]

1: **Fused Deposition Modeling (FDM) in Personalized Medicine:**

Principle:

Fused Deposition Modeling, which is also known as FDM is a way of making things using melted plastic. This Fused Deposition Modeling process works by heating up strings of plastic called polymer filaments until they are really hot and melty. These polymer filaments have medicine in them. When they are hot, they get pushed through a hot tube called a nozzle. This nozzle helps make the Fused Deposition Modeling process work. The hot plastic then gets built up layer by layer to make a shape, kind of like building with blocks but following instructions, from a computer.[41]

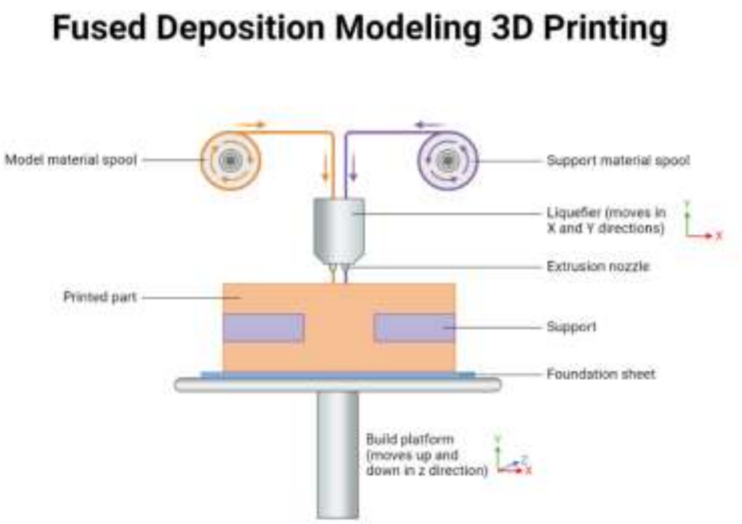

Fig. 1: **Fused Deposition Modeling (FDM) in Personalized Medicine**

CONSTRUCTION:

Construction of an FDM printer is pretty interesting:
An FDM printer is made up of important parts. These are:

- Filament spool holder
- extrusion nozzle
- Extruder motor
- Build platform
- Temperature control system
- Computer, with CAD software [41,42]

The FDM printer has all these parts that work together to create something. The FDM printer is a machine.
Commonly used polymers include:

- Polyvinyl alcohol (PVA)
- Polylactic acid (PLA)
- Hydroxypropyl cellulose (HPC)
- Ethyl cellulose
- Eudragit polymers [42]

Working:

1. We mix the drug and polymer well.
2. Then we use a hot-melt extrusion method to make a filament that has the drug in it.
3. Next we put the filament into a nozzle.
4. The polymer. Gets layered, on top of itself.
5. Each layer hardens to create the medicine form [42,43].

Advantages:

- It allows for easy dose customization
- You can modify the drug release profile
- It helps in making shapes
- It is good for making things on demand
- It has high mechanical strength [43]

Disadvantages:

- The high temperature used can harm some drugs
- There are not many types of safe polymers for medicine
- It takes a long time to print
- The nozzle can get blocked [44]

Applications:

- Tablets that release medicine slowly
- Tablets that stay in the stomach
- Tablets that float
- Pills with many medicines
- Medicine, for kids
- Custom implants [43,44]

FDM is really good, for medicine. This is because we can change the tablet size, how much material is used inside and its shape to fit what each patient needs. This technology helps make oral medicines for each person. These medicines can be made to release the drug at a rate and can have different drugs combined in one tablet. [45]

2. **Stereolithography (SLA) in Personalized Medicine:**

Principle:

Stereolithography or SLA works by using a kind of light.
This light is called ultraviolet or UV laser light.
It helps to turn resin into solid parts, one layer at a time.
The resin is a liquid that gets hard when it meets the UV light.
This process is called photopolymerization.
It makes structures bit by bit layer, by layer [46].

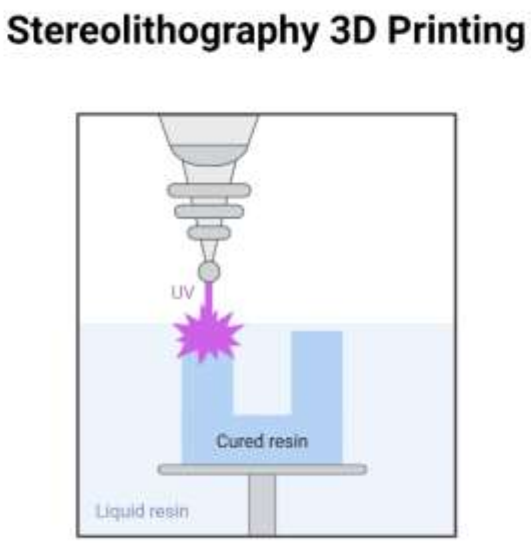

Fig. 2: Stereolithography (SLA) in Personalized Medicine

Construction:
The SLA printer has main parts:
- A resin container
- A UV laser
- An optical mirror
- A movable build stage
- CAD software [46]

Working:
- The build stage is put in the resin.
- The UV laser scans areas based on the CAD design.
- The resin turns into a solid.
- The stage moves down after each layer is done.
- This process keeps going until the whole object is made. [46,47]

Advantages:

- This method has precision and accuracy.
- It gives a smooth surface finish.
- It creates high-resolution structures.
- It is suitable for biomedical devices. [47]

Disadvantages:
- The equipment is expensive.
- There are biocompatible photopolymers available.
- There is a risk of resin toxicity.
- Post-curing is required.
- Dental prosthetics
- Microneedles
- Hearing aids
- Tissue engineering scaffolds
- Customized implants [47]

SLA technology is widely used for making patient- implants and biomedical devices because it has superior accuracy and dimensional precision. This technology is highly beneficial, in medicine and tissue engineering applications. [48]

3. Selective Laser Sintering (SLS) in Personalized Medicine:

Principle:

The way Selective Laser Sintering works is that it uses a laser to melt and fuse together materials one layer at a time. This process is called sintering. Selective Laser Sintering is a method that builds things from these powdered materials.

Fig. 3: Deckard CR. *Method and apparatus for producing parts by selective sintering*.

Construction:

The SLS system is pretty interesting. The SLS system consists of important parts these are:

- Powder bed chamber which is a crucial part of the SLS system
- Roller or spreader that helps in the process
- Laser source that does the main work
- Build platform where everything comes together
- Heating chamber that provides the necessary heat
- CAD software which is used to design the SLS system [49]

Working:

When it comes to working of the SLS system it is a step-by-step process.

- A layer of powder is spread over the build platform.
- The laser source then selectively sinters the powder particles this is a step in the SLS system.
- After that the build platform moves downward making room for the layer.
- A fresh layer of powder is. The SLS system is ready, for the next step.

The SLS system goes through repeated cycles. Finally, it produces the final dosage form, which is the end result of the SLS system [49,50].

Advantages:

- Personalized Medicine has a solvent free process
- Personalized Medicine has high mechanical strength which is very good
- Personalized Medicine allows for production.
- Personalized Medicine is suitable for porous dosage forms [50]

Disadvantages:

- The equipment for Personalized Medicine is expensive
- There is a risk of degradation in Personalized Medicine
- It is difficult to optimize the process of Personalized Medicine [50]

Applications:

- Personalized Medicine is used for Oro tablets
- Personalized Medicine is used for controlled release formulations

- Personalized Medicine is used for implants
- Personalized Medicine is used for porous scaffolds [50]

Personalized Medicine made with SLS technology can create very porous structures that can be customized to release drugs in different ways. This method is particularly useful, for making personalized dosage forms that break down quickly [51].

4. Inkjet Printing / Binder Jetting in Personalized Medicine:

Principle:
Inkjet printing or binder jetting works by putting binder drops on powder beds to bind particles layer by layer. [38]

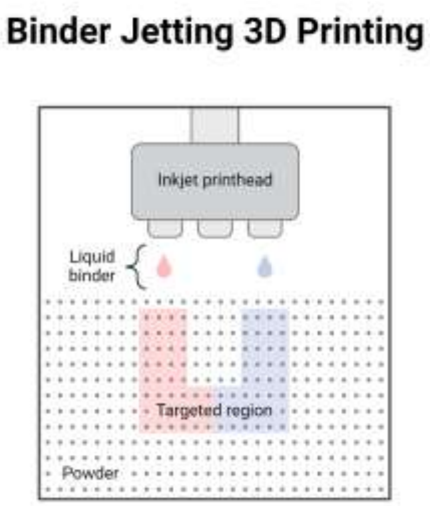

Fig. 4: Inkjet Printing / Binder Jetting in Personalized Medicine

Construction:
The printer has:
- An inkjet print head
- A powder bed
- A binder reservoir
- A roller or spreader
- A build platform
- CAD software [38]

Working:
- The powder layer is spread out evenly.
- The binder solution is sprayed on in areas.
- The powder particles stick together.
- The platform moves down after each layer.
- The final product forms, after cycles.[51]

Advantages:
- We can get the dose right
- The medicine breaks down really fast
- The tablets are very porous
- They are good for strong medicines [51]

Disadvantages:
- The tablets are not very strong
- They do not like moisture
- We need to dry them some more [51]

Applications:

- Tablets that melt in your mouth
- Medicines that dissolve fast
- We can make special doses for each person
- The FDA likes Sprit am tablets [38]

Binder jetting technology is really good, for older people and kids because it makes tablets that break down fast and are made just for them so they are more likely to take their medicine as they should [52].

5. Semi-Solid Extrusion (SSE) in Personalized Medicine:

Principle:

Principle Semi-solid extrusion is based on pushing gels, pastes or semi-solid mixtures through a nozzle.
This is done using air pressure or a machine.
It works with -solid extrusion.
Gels, pastes or semi-solid formulations are used.
The process uses a nozzle and pneumatic or mechanical pressure.[53]

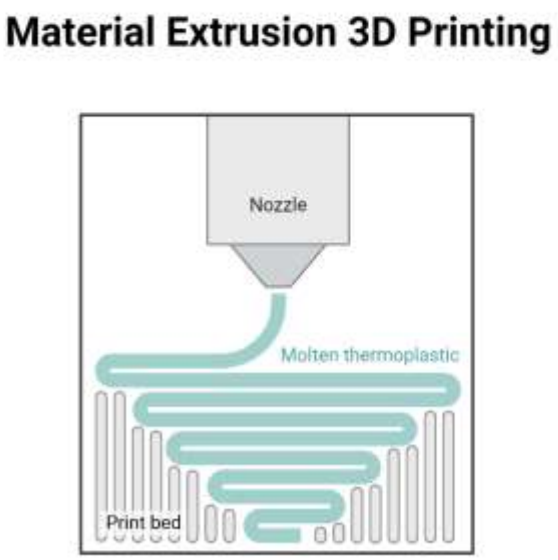

Fig. 5: **Semi-Solid Extrusion (SSE) in Personalized Medicine:**

construction:

this machine is pretty interesting. The main parts that make it work include:

- A special container called a syringe or cartridge system
- A pipe called an extrusion nozzle
- A system that uses air pressure called a pneumatic pressure system
- A base where things are built called a build platform
- Special computer software called CAD software[53]

Working:

When it is working here is what happens:

- A special mix that is not too liquid and not too solid is put into the syringe.
- The air pressure system pushes this mix through the pipe.
- The mix is added layer by layer to create something.
- What is printed becomes solid when it dries or cools down.[53]

Advantages:

- It is good for medicines that cannot handle high temperatures
- It works at low temperatures
- It is easy to change the mix of the medicine
- It helps to keep the medicine from breaking down [53]

Disadvantages:
- The things it makes are not very strong
- The mix has to be just right or it will not work
- It takes a long time to make things [53]

Application:
- Special gels that are full of water
- Medicines that you put on your skin
- Tablets that you can chew
- New tissues for your body
- Special things that are printed with living cells

The machine is very flexible. Can make many different kinds of medicines especially for kids, old people and medicines that are sensitive, to temperature and need to be made just for one person.[54]

Materials Used in 3D Printing for Personalized Medicine:

Materials are really important for three- printing. The quality of the product how strong it is, how it releases drugs if it is safe for the body and if it is stable all depend on the material that is chosen.[55]
When it comes to making medicines and medical things the materials used for three- printing have to be just right. They need to have the physical and chemical properties be able to be printed be safe for the body break down naturally and work well with drugs.[56]
We use different kinds of materials for three-dimensional printing, like polymers, hydrogels, metals, ceramics and biomaterials. These materials are used with printing methods, such as Fused Deposition Modeling, Stereolithography, Selective Laser Sintering, Inkjet Printing and Semi-Solid Extrusion.[57]
Choosing the material is crucial for getting the desired results, like how the drug is released how strong the product is, if it is stable and if it works well for each patient. Three-dimensional printing materials, like these have to be selected to get the best results.[58]

Types of Materials Used in 3D Printing:

1) Polymers:

Polymers are really useful in 3D printing. The reason Polymers are used much is that Polymers are flexible and safe for the body. Polymers are also easy to work with.[59]
Polymers that come from nature and Polymers that are made in a lab are both used to make medicines and medical devices that are just for one person.

Commonly Used Polymers;
- Polyvinyl alcohol (PVA)
- Polylactic acid (PLA)
- Polycaprolactone (PCL)
- Hydroxypropyl methylcellulose (HPMC)
- Hydroxypropyl cellulose (HPC)
- Ethyl cellulose
- Polyethylene glycol (PEG)
- Eudragit polymers [59]

2) HYDROGEL:

Hydrogels are really cool. They are like networks that can hold a lot of water. Hydrogels are made up of parts that love water so they can absorb a lot of it without falling apart.[62]
Hydrogels are very useful in things like bioprinting and tissue engineering because they are similar, to the stuff that surrounds cells in our body, which is called the matrix of biological tissues. Hydrogels are used a lot in these fields because of this.

Common Hydrogel Materials
- Alginate
- Gelatine
- Chitosan
- Hyaluronic acid
- Collagen
- Polyacrylamide [62]

3) Metals:

Metals are mainly used in biomedical and orthopaedic applications due to their superior mechanical strength and durability [65].

Commonly Used Metals

- Titanium
- Stainless steel
- Cobalt-chromium alloys
- Gold
- Silver [65]

4) Ceramics

Ceramics are really good for making things that can help our bodies. They are used a lot in bone tissue engineering and regenerative medicine. This is because ceramics are very friendly to our bodies and they can help our bones grow. They have something called biocompatibility and osteoconductive properties [68]. Ceramics are great, for this kind of thing.

Common Ceramic Materials

- Hydroxyapatite
- Tricalcium phosphate
- Zirconia
- Alumina [68]

5) Biomaterials and Bioinks:

Bioinks are specialized biomaterials containing living cells, biomolecules, and supportive matrices used in bioprinting technologies [70].

Components of Bioinks

- Living cells
- Growth factors
- Hydrogels
- Biomolecules
- Extracellular matrix materials [70]

Challenges of 3D Printing in Medicine:

3D printing in personalized medicine has a lot of benefits but there are many challenges that stop it from being used more widely in the pharmaceutical industry. One big problem is that there are not materials that are good enough for 3D printing and can be used to make medicine. [71] Many of the materials that are used now for printing may not be safe for people or strong enough for pharmaceutical applications.[72]

Another big issue is the temperature that is needed for some 3D printing methods like Fused Deposition Modeling. This high temperature can damage some medicines.[73] Affect how well they work. It is also hard to make sure that the right amount of medicine is in each dose for medicines that are only needed in small amounts.

The cost of printers and the materials and software that are needed to run them is also a big problem. It is expensive to buy and maintain these machines. [74] The 3D printing process is also slower than the ways that medicines are usually made which makes it hard to make quantities of medicine.[75]

There are also problems with regulations for 3D printing in the pharmaceutical industry. There are not rules that say how 3D printed medicines should be made and tested to make sure they are safe and work well. The way that 3D printing is done can affect how well the medicine works.[76]

For example, the temperature and speed of the printer can change how the medicine is released and how well it works. [77] The 3D printed medicines can also be affected by how they're stored and handled. Some of them are sensitive to moisture. Can become weak or unstable over time.[78]

It is also important to have trained people who know how to use the printing machines and can make sure that they are working correctly. This can increase the cost of making printed medicines. [78,79]

There are also concerns about keeping information and digital prescriptions safe when they are used for 3D printing. These are issues that need to be addressed. [80,81]

With all these challenges people are working to improve 3D printing, in personalized medicine. They are developing materials and better ways of making 3D printed medicines. They are also working on regulations and rules to make sure that 3D printed medicines are safe and effective.[82]

FUTURE SCOPE:

The future of printing in personalized medicine looks very promising. This is because of advancements in intelligence smart biomaterials, nanotechnology and 4D printing technologies. [84,85]
Integration of intelligence with 3D printing will change how medicines are made. It will help design medicines predict how patients will respond to drugs and monitor the printing process.[86] AI will help make medicines tailored to each patient based on their profile, disease, age and health. This will make treatments more precise. Reduce mistakes. [87,88]
Another important advancement is 4D printing. It is like 3D printing. Uses smart materials that can change shape or properties over time.[89] These materials can respond to temperature, pH, light or other external stimuli. 4D printing may lead to drug delivery systems that release drugs as needed inside the body. Future applications may include self-folding implants and responsive tissue scaffolds.[90]
Bioprinting and tissue engineering will also play a role in healthcare. Advanced 3D bioprinting may enable fabrication of tissues, skin grafts and even functional organs. These advancements may improve regenerative medicine organ transplantation and cancer research.[91]
The integration of nanotechnology with 3D printing may result in smart drug delivery systems. These systems will have improved bioavailability, targeted drug delivery and enhanced therapeutic efficacy. Future healthcare systems may establish hospital-based or pharmacy-based printing units. These units will manufacture medicines on demand. [92]
Despite challenges technological advancements are expected to make 3D printing essential in future precision medicine and patient-centred healthcare systems. Printing and artificial intelligence will continue to advance. 3D printing will play a role, in the future of healthcare. 3D printing technology is expected to improve healthcare.[84]

Conclusion:
Three-dimensional printing is a cool thing that is changing the way we make medicine. It lets us make specific dosage forms that are just right for each person. This is different from the way of making medicine, where everyone gets the same amount. With three printing we can make the dose, shape, size and how the drug is released just right for each patient.
There are a lot of ways to do three-dimensional printing, like Fused Deposition Modeling, Stereolithography, Selective Laser Sintering, Binder Jetting and Semi-Solid Extrusion. These methods are really good at making medicines, implants, tissue scaffolds and advanced drug delivery systems. They help people get the amount of medicine and they make it easier for patients to take their medicine.
Three-dimensional printing has also made it possible to make medicine that's just right for each person. It has improved how well the medicine works. It has made it easier for patients to take the right dose. It has also helped with something called polypharmacy which's when patients have to take a lot of different medicines.
In the future we can expect to see more changes with things like artificial intelligence, nanotechnology, bioprinting and four-dimensional printing. These things will help make medicine that's smart and just right for each patient. Even though there are still some challenges like figuring out the rules and making it cheaper three-dimensional printing is going to keep getting better.
Overall three-dimensional printing is an exciting thing that is going to change the way we make medicine. It is going to make it possible to make medicine that's just right, for each person and it is going to help us take care of people in a better way. Three-dimensional printing is going to be a part of personalized medicine and precision healthcare and it is going to help us make new medicines and take care of diseases in a better way. Three-dimensional printing is really going to change the way we think about medicine and how we take care of people.

REFERENCES:
1) Mishra J, Kar Pillai M, Jain S, Manocha N. Additive manufacturing excellence: A review of 3D printing process in precise drug delivery for personalized medicine. SEEJPH, 2025; XXVI(S1): 2918-2930.
2) Dong C, Petrovic M, Davies IJ. Applications of 3D printing in medicine: A review. Ann 3D Print Med, 2024; 14: 100149.

3) Vaz VM, Kumar L. 3D printing as a promising tool in personalized medicine. AAPS Pharm SciTech, 2021; 22: 49.
4) Vaz VM, Kumar L. 3D printing as a promising tool in personalized medicine. AAPS Pharm SciTech, 2021; 22: 49.
5) Tren field, S.J., Awad, A., Goyanes, A., Gaisford, S., and Basit, A.W. (2018). 3D printing pharmaceuticals: drug development to frontline care. Trends Pharmacal. Sci. 39, 440–451.
6) Xu, Y., Zhang, F., Zhai, W., Cheng, S., Li, J., and Wang, Y. (2022). Un raveling of advances in 3D-printed polymer-based bone scaffolds. Polymers 14, 566.
7) Kotta S, Nair A, Alsabeelah N. 3D printing technology in drug delivery: recent progress and application. Curr Pharm Des, 2018; 24: 5039-5048
8) Samiei N. Recent trends on applications of 3D printing technology on the design and manufacture of pharmaceutical oral formulation: a mini review. Beni-Suef Univ J Basic Appl Sci, 2020; 9: 12
9) European Commission Personalised Medicines. Available online: https://research-and-innovation.ec.europa.eu/research-area/health/personalised-medicine_en (accessed on 9 November 2022).
10) Nimmesgern, E.; Norstedt, I.; Draghia-Akli, R. Enabling personalized medicine in Europe by the European Commission's funding activities. Pers. Med. 2017, 14, 355–365.
11) Nimmesgern, E.; Benediktsson, I.; Norstedt, I. Personalized Medicine in Europe. Clin. Transl. Sci. 2017, 10, 61–63.
12) Ye, M., Zhou, Y., Zhao, H., and Wang, X. (2023). Magnetic microrobots with folate targeting for drug delivery. Cyborg. Bionic. Syst. 4, 19. https://doi.org/10.34133/cbsystems.0019.
13) Lee, H. (2023). Engineering in vitro models: Bioprinting of organoids with artificial intelligence. Cyborg. Bionic. Syst. 4, 18. https://doi.org/10. 34133/cbsystems.0018.
14) Tucker GT. Personalized drug dosage – closing the loop. *Pharm Res.* 2017; 34:1539–1543.
15) Alhnan MA, Okwuosa TC, Sadia M, Wan KW, Ahmed W, Arafat B. Emergence of 3D printed dosage forms. *Pharm Res.* 2016;33(8):1817–1832.
16) Pereira BC, Isreb A, Forbes RT, Dores F, Habashy R, Petit JB, et al. 3D printed patient-centred cardiovascular polypill architectures. *Eur J Pharm Bio pharm.* 2019; 135:94–103
17) Khaled SA, Burley JC, Alexander MR, Yang J, Roberts CJ. 3D printing of five-in-one dose combination polypill. *Nat Commun.* 2015; 6:1–9.
18) Khaled SA, Alexander MR, Irvine DJ, Wildman RD, Wallace MJ, Sharpe S, et al. Extrusion 3D printing of paracetamol tablets. *Int J Pharm.* 2018;538(1–2):223–230.
19) Melocchi A, Parietti F, Loreti G, Maroni A, Gazzaniga A, Zema L. 3D printing by fused deposition modeling of oral delivery systems. *AAPS PharmSciTech.* 2018;19(5):2478–2488.
20) Skowyra J, Pietrzak K, Alhnan MA. Fabrication of extended-release tablets using fused deposition modelling. *Eur J Pharm Sci.* 2015; 68:11–17
21) Scoutaris N, Ross S, Douroumis D. 3D printed dosage forms for pediatric applications. *Pharm Res.* 2018;35(2):34.
22) El Aita I, Rahman J, Breitkreutz J, Quodbach J. Pressure-assisted micro syringe printing for pediatric medicines. *Eur J Pharm Bio pharm.* 2020; 157:59–65.
23) Awad A, Trenfield SJ, Goyanes A, Gaisford S, Basit AW. Reshaping drug development using 3D printing technology. *Drug Discov Today.* 2018;23(8):1547–1555.
24) Javaid M, Haleem A. Additive manufacturing applications in healthcare. *J Clin Orthop Trauma.* 2019;10(4):660–670.
25) Radhakrishnan A, Kuppusamy G, Ponnu Sankar S, et al. Pharmacogenomic phase transition from personalized medicine to patient-centric delivery. *Pharmacogenomics J.* 2020; 20:1–18.
26) Seoane-Viaño I, Januskaite P, Alvarez-Lorenzo C, Basit AW, Goyanes A. Semi-solid extrusion 3D printing in personalized medicine. *Adv Drug Deliv Rev.* 2021; 176:113840
27) Fina F, Goyanes A, Madla CM, Awad A, Trenfield SJ, Kuek JM, et al. Selective laser sintering for drug delivery systems. *Int J Pharm.* 2018;547(1–2):44–52.
28) Wang J, Goyanes A, Gaisford S, Basit AW. Stereolithographic 3D printing of oral dosage forms. *Int J Pharm.* 2016;503(1–2):207–212.
29) Murphy SV, Atala A. 3D bioprinting of tissues and organs. *Nat Biotechnol.* 2014;32(8):773–785.
30)) Steffen JA, Steffen JS. Personalized medicine and healthcare advancement. *J Pers Med.* 2013;3(1):14–22.

31) Javaid M, Haleem A. Current status of additive manufacturing in healthcare. *J Clin Orthop Trauma.* 2019;10(4):660–670.
32)) Offit K. Personalized medicine: new genomics, old lessons. *Hum Genet.* 2011; 130:3–14.
33) Vaz VM, Kumar L. 3D printing as a promising tool in personalized medicine. *AAPS PharmSciTech.* 2021; 22:49.
34) Trenfield SJ, Awad A, Goyanes A, Gaisford S, Basit AW. 3D printing pharmaceuticals: drug development to frontline care. *Trends Pharmacol Sci.* 2018;39(5):440–451.
35) Jamróz W, Szafraniec J, Kurek M, Jachowicz R. 3D printing in pharmaceutical and medical applications – recent achievements and challenges. *Pharm Res.* 2018;35(9):176.
36) Norman J, Madurawe RD, Moore CMV, Khan MA, Khairuzzaman A. A new chapter in pharmaceutical manufacturing: 3D-printed drug products. *Adv Drug Deliv Rev.* 2017; 108:39–50.
37) Katstra WE, Palazzolo RD, Rowe CW, Giritlioglu B, Teung P, Cima MJ. Oral dosage forms fabricated by Three-Dimensional Printing™. *J Control Release.* 2000;66(1):1–9.
38) Alhnan MA, Okwuosa TC, Sadia M, Wan KW, Ahmed W, Arafat B. Emergence of 3D printed dosage forms. *Pharm Res.* 2016;33(8):1817–1832.
39) Trenfield SJ, Awad A, Goyanes A, Gaisford S, Basit AW. 3D printing pharmaceuticals: drug development to frontline care. *Trends Pharmacol Sci.* 2018;39(5):440–451.
40) Khaled SA, Burley JC, Alexander MR, Yang J, Roberts CJ. 3D printing of five-in-one dose combination polypill. *Nat Commun.* 2015; 6:1–9.
41) Goyanes A, Buanz ABM, Basit AW, Gaisford S. Fused-filament 3D printing for fabrication of tablets. *Int J Pharm.* 2014;476(1–2):88–92.
42) Pereira BC, Isreb A, Forbes RT, Dores F, Habashy R, Petit JB, et al. 3D printed patient-centred cardiovascular polypill architectures. *Eur J Pharm Bio pharm.* 2019; 135:94–103.
43) Skowyra J, Pietrzak K, Alhnan MA. Fabrication of extended-release tablets using fused deposition modelling. *Eur J Pharm Sci.* 2015; 68:11–17.
44) Goole J, Amighi K. 3D printing in pharmaceutics: A new tool for customized drug delivery systems. *Int J Pharm.* 2016;499(1–2):376–394.
45) Melocchi A, Parietti F, Loreti G, Maroni A, Gazzaniga A, Zema L. 3D printing by fused deposition modeling of oral delivery systems. *AAPS PharmSciTech.* 2018;19(5):2478–2488.
46) Wang J, Goyanes A, Gaisford S, Basit AW. Stereolithographic 3D printing of oral modified-release dosage forms. *Int J Pharm.* 2016;503(1–2):207–212.
47) murphy SV, Atala A. 3D bioprinting of tissues and organs. *Nat Biotechnol.* 2014;32(8):773–785.
48) Javaid M, Haleem A. Current status and applications of additive manufacturing in healthcare. *J Clin Orthop Trauma.* 2019;10(4):660–670.
49) Fina F, Goyanes A, Madla CM, Awad A, Trenfield SJ, Kuek JM, et al. 3D printing of drug-loaded gyroid lattices using selective laser sintering. *Int J Pharm.* 2018;547(1–2):44–52.
50) Awad A, Fina F, Goyanes A, Gaisford S, Basit AW. Pharmaceutical applications of selective laser sintering. *Int J Pharm.* 2020; 586:119594.
51) Rowe CW, Katstra WE, Palazzolo RD, Giritlioglu B, Cima MJ. Mult mechanism oral dosage forms fabricated by Three-Dimensional Printing™. *J Control Release.* 2000;66(1):11–17.
52) Scoutaris N, Ross S, Douroumis D. 3D printed dosage forms for paediatric applications. *Pharm Res.* 2018;35(2):34
53) Seoane-Viaño I, Januskaite P, Alvarez-Lorenzo C, Basit AW, Goyanes A. Semi-solid extrusion 3D printing in drug delivery and personalized medicine. *Adv Drug Deliv Rev.* 2021; 176:113840.
54) El Aita I, Rahman J, Breitkreutz J, Quodbach J. 3D printing for pediatric medicines using pressure-assisted micro syringe printing. *Eur J Pharm Bio pharm.* 2020; 157:59–65.
55) Jamróz W, Szafraniec J, Kurek M, Jachowicz R. 3D printing in pharmaceutical and medical applications – recent achievements and challenges. *Pharm Res.* 2018;35(9):176.
56) Trenfield SJ, Awad A, Goyanes A, Gaisford S, Basit AW. 3D printing pharmaceuticals: drug development to frontline care. *Trends Pharmacol Sci.* 2018;39(5):440–451.
57) Goole J, Amighi K. 3D printing in pharmaceutics: customized drug delivery systems. *Int J Pharm.* 2016;499(1–2):376–394.
58) Vaz VM, Kumar L. 3D printing as a promising tool in personalized medicine. *AAPS Pharm SciTech.* 2021; 22:49.

59) Goyanes A, Buanz ABM, Basit AW, Gaisford S. Fused-filament 3D printing for fabrication of tablets. *Int J Pharm.* 2014;476(1–2):88–92.
60) Melocchi A, Parietti F, Loreti G, Maroni A, Gazzaniga A, Zema L. 3D printing by fused deposition modeling of oral delivery systems. *AAPS PharmSciTech.* 2018;19(5):2478–2488.
61) Alhnan MA, Okwuosa TC, Sadia M, Wan KW, Ahmed W, Arafat B. Emergence of 3D printed dosage forms. *Pharm Res.* 2016;33(8):1817–1832.
62) Murphy SV, Atala A. 3D bioprinting of tissues and organs. *Nat Biotechnol.* 2014;32(8):773–785.
63) Mandrycky C, Wang Z, Kim K, Kim DH. 3D bioprinting for engineering complex tissues. *Biotechnol Adv.* 2016;34(4):422–434.
64) Miao S, Castro N, Nowicki M, Xia L, Cui H, Zhou X, et al. 4D printing of polymeric materials for tissue regeneration. *Mater Today.* 2017;20(10):577–591.
65) Javaid M, Haleem A. Additive manufacturing applications in healthcare. *J Clin Orthop Trauma.* 2019;10(4):660–670.
66) Wang X, Jiang M, Zhou Z, Gou J, Hui D. 3D printing of polymer matrix composites. *Compos Part B Eng.* 2017; 110:442–458.
67) Norman J, Madurawe RD, Moore CMV, Khan MA, Khairuzzaman A. A new chapter in pharmaceutical manufacturing: 3D-printed drug products. *Adv Drug Deliv Rev.* 2017; 108:39–50.
68) Bose S, Vahabzadeh S, Bandyopadhyay A. Bone tissue engineering using 3D printing. *Mater Today.* 2013;16(12):496–504.
69) Derby B. Printing and prototyping of tissues and scaffolds. *Science.* 2012;338(6109):921–926.
70) Hospodiuk M, Dey M, Sosnoski D, Ozbolat IT. The bioink: a comprehensive review on bioprintable materials. *Biotechnol Adv.* 2017;35(2):217–239.
71) Cui X, Boland T. Human microvasculature fabrication using thermal inkjet printing technology. *Biomaterials.* 2009;30(31):6221–6227.
72) Alhnan MA, Okwuosa TC, Sadia M, Wan KW, Ahmed W, Arafat B. Emergence of 3D printed dosage forms. *Pharm Res.* 2016;33(8):1817–1832.
73) Goole J, Amighi K. 3D printing in pharmaceutics: A new tool for designing customized drug delivery systems. *Int J Pharm.* 2016;499(1–2):376–394.
74) Goyanes A, Buanz ABM, Basit AW, Gaisford S. Fused-filament 3D printing for fabrication of tablets. *Int J Pharm.* 2014;476(1–2):88–92.
75) Khaled SA, Burley JC, Alexander MR, Yang J, Roberts CJ. 3D printing of five-in-one dose combination polypill. *Nat Commun.* 2015; 6:1–9.
76) Awad A, Trenfield SJ, Goyanes A, Gaisford S, Basit AW. Reshaping drug development using 3D printing technology. *Drug Discov Today.* 2018;23(8):1547–1555.
77) Norman J, Madurawe RD, Moore CMV, Khan MA, Khairuzzaman A. A new chapter in pharmaceutical manufacturing: 3D-printed drug products. *Adv Drug Deliv Rev.* 2017; 108:39–50.
78) Trenfield SJ, Awad A, Goyanes A, Gaisford S, Basit AW. 3D printing pharmaceuticals: drug development to frontline care. *Trends Pharmacol Sci.* 2018;39(5):440–451.
79) Melocchi A, Parietti F, Loreti G, Maroni A, Gazzaniga A, Zema L. 3D printing by fused deposition modeling of oral delivery systems. *AAPS PharmSciTech.* 2018;19(5):2478–2488.
80) Seoane-Viaño I, Januskaite P, Alvarez-Lorenzo C, Basit AW, Goyanes A. Semi-solid extrusion 3D printing in drug delivery and personalized medicine. *Adv Drug Deliv Rev.* 2021; 176:113840.
81) Jamróz W, Szafraniec J, Kurek M, Jachowicz R. 3D printing in pharmaceutical and medical applications – recent achievements and challenges. *Pharm Res.* 2018;35(9):176.
82) Vaz VM, Kumar L. 3D printing as a promising tool in personalized medicine. *AAPS PharmSciTech.* 2021; 22:49.
83) Javaid M, Haleem A. Additive manufacturing applications in healthcare: A review. *J Clin Orthop Trauma.* 2019;10(4):660–670
84) Trenfield SJ, Awad A, Goyanes A, Gaisford S, Basit AW. 3D printing pharmaceuticals: drug development to frontline care. *Trends Pharmacol Sci.* 2018;39(5):440–451.
85) Marques L, Costa B, Pereira M, et al. Advancing precision medicine using artificial intelligence and digital technologies. *Pharmaceutics.* 2024;16(3):332.
86) Awad A, Trenfield SJ, Goyanes A, Gaisford S, Basit AW. Reshaping drug development using 3D printing technology. *Drug Discov Today.* 2018;23(8):1547–1555.

87) Gladman AS, Matsumoto EA, Nuzzo RG, Mahadevan L, Lewis JA. Biomimetic 4D printing. *Nat Mater.* 2016;15(4):413–418.
88) Miao S, Castro N, Nowicki M, Xia L, Cui H, Zhou X, et al. 4D printing of polymeric materials for tissue and organ regeneration. *Mater Today.* 2017;20(10):577–591.
89) Murphy SV, Atala A. 3D bioprinting of tissues and organs. *Nat Biotechnol.* 2014;32(8):773–785.
90) Mandryk C, Wang Z, Kim K, Kim DH. 3D bioprinting for engineering complex tissues. *Biotechnol Adv.* 2016;34(4):422–434.
91) Goole J, Amighi K. 3D printing in pharmaceutics: customized drug delivery systems. *Int J Pharm.* 2016;499(1–2):376–394.
92) Norman J, Madurawe RD, Moore CMV, Khan MA, Khairuzzaman A. A new chapter in pharmaceutical manufacturing: 3D-printed drug products. *Adv Drug Deliv Rev.* 2017; 108:39–50.