IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

3D PRINTING: AN ADVANCED TECHNOLOGY IN TAILORED DRUG DELIVERY SYSTEM

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Abstract

In today's pharmaceutical industry, the 3D printing process is a highly dynamic approach. It is the pursuit of the most up-to-date concepts in medication development in order to better understanding the quality of raw materials and the manufacturing process. It is the fastest technology in the modern era. It benefits in a variety of ways, including lowering the need for prototyping, saving time and money, and facilitating process adjustment. It is a powerful and flexible production tool. It also aids in the formulation of a Novel Drug Delivery System (NDDS). It has been used in the production of pharmaceutical solid dosage forms as well as combinations of solid and liquid dosage forms. Many technologies are emerging to facilitate the paradigm change from traditional "one size fits all" care to personalized medicine, the most important of which being three-dimensional (3D) printing. It is primarily used to create personalized medicine, which is a mixture of various pharmaceutical ingredients used in the treatment of various diseases. This technology is now being used by several pharmaceutical vendors to supply patients with personalized medical treatments on a daily basis. This technique has also been used to modify the release profiles of other drugs, such as to create sustained and extended-release formulations. We concluded from the available data that the 3D printing is a versatile approach that is now being used to improve the utilization of combination therapy. In the future, prescriptions could be dispensed based on individual needs in a therapeutic setting.

Keyword: 3D Printing, Additive Manufacturing, Customization, Personalization, Personalized Medicine

Introduction

The technology and formulation designed to efficiently transport a pharmacologically active molecule in the body in order to achieve therapeutic efficiency in a safe manner is known as drug delivery. Controlling the release profile, which modifies the pharmacokinetics of a drug, can increase the efficiency and safety of a pharmaceutical product. Inter-species diversity is a common major obstacle in clinical practice. Because of the significant risk of unfavorable side effects, personalized therapy and dosing is increasing in popularity. When the bulk manufacturing of drugs focuses on the average population, the risk of adverse responses is higher in the pediatrics and geriatric groups. Multiple active ingredient dosage forms, where the formulation can be as a single blended or multi layered printed tablets with sustained release properties, can improve from 3D printing. This minimizes the frequency and number of dosage form units administered on a daily basis by the patient. The polypill concept, which uses 3D printing technology to create personalized dose forms, has a lot of potential. This allows all of the medications needed for the therapy to be combined into a single dose form unit. [4] 3D printing is an innovative rapid prototyping technique in which solid objects are manufactured by depositing multiple layers in a sequential order. Rapid prototyping is the process of creating physical models in three dimensions using computer-aided design. It's also known as solid free form fabrication or additive manufacturing. 3D printing has given designers and manufacturers remarkable flexibility in the design and manufacture of complex items, which can be used in personalized and programmed medicine. It's an efficient strategy to have around some of the issues that come with running a traditional pharmaceutical industry. [4]

History of 3D Printing

The first 3D printing research dates back to the late 1970s, when numerous patents for computer-aided additive manufacturing techniques using various platforms were registered. Stereo Lithography (SLA), one of the key technologies in 3D printing, was discovered and patented in the mid-1980s by Charles (Chuck) Hull, who is also known as the inventor of this technique. To achieve a desired object, UV light had been used to polymerize resins. 3D Systems, which Hull invented, proceeded further to commercialize these SLA printers.

Carl Deckard, a Texas university student, invented another technology called Selective laser sintering in 1986, which used a laser to fuse powder together. Scott and Lisa Crump of the company Strategy's registered another patent for fused deposition modeling in 1989.

Using a nozzle, this method required heating and moulding plastic or metal. Later in 1989, Emanuel Sachs and his colleagues at MIT developed "3D printing," which used a binding solution extruded on a powder bed and were created by altering an inkjet printer. The technique became known as "Binder Jetting" later on. In 1989, Hans Langer focused on direct metal laser sintering, which used a laser to create 3D things based on computer models. Various attempts were undertaken in order for consumers to be able to obtain low-cost, non-proprietary printers. Andrew Bowyer of the University of Bath created and coordinated the Rep Rap project, which involved producing 3D printers that manufacture the majority of their own components and then expanding through multiple collaborations. 3D printing technology has been used in a variety of fields since its debut. Surgical planning and guidance, as well as implant production, were the first clinical uses in healthcare. Implants containing active pharmacological ingredients have also been produced, with good customization potential. 3D printing has also been used in clinical education. 3D printing has now made its way into the pharmaceutical industry, where it is being utilized to create a variety of dosage forms. The FDA authorized Spritam (Levetiracetam), a prescription medicine for epilepsy produced by Aprecia Pharmaceuticals, as the first 3D printed drug in 2015. Because of its very porous nature, this was made utilizing the binder jet printing method and is capable of quick oral dissolution.

Advantages

1. The ability to obtain high drug loading with the precision and accuracy required, particularly for strong medications administered in small doses. [14, 5]
2. Flexibility in the design, development, and manufacture of single or multi-drug formulations with built-in immediate and controlled-release layers that can be customized to the specific needs of individual patients. [14]
3. High repeatability, quick and precise manufacturing, customized product series, superficial alterations of a product at the intended level with no limits on its spatial configuration, and simple, cost-effective manufacturing [15]
4. **Enhanced Productivity:** 3D printing is safer than conventional methods, with the added benefit of better resolution, repeatability, accuracy, and reliability. [4]
5. **Customization and Personalization:** The ability to create personalized medical equipment and products. Patients and doctors alike can benefit from customized implants, prosthetics, surgical instruments, and fixtures. [4]
6. **Increased cost effectiveness:** 3D printed objects are inexpensive. Because practically all materials are affordable, it is advantageous for small-scale production units or organizations that make very complicated products or parts. For example, depending on the situation, 20-mg tablets could be reformulated as 1-mg tablet. [4]
7. Enhances the safety, potency, and accessibility of medicines, as well as dose optimization. [12, 16]
8. Effective medication delivery for active components that is difficult to manufacture, such as those with low aqueous solubility or medicines with a narrow therapeutic window. [5]
9. Medication can be customized for a specific patient based on genetic variances, ethnic differences, age, gender, and environmental factors. [5]
10. Eliminates batch-to-batch variability inherent in conventional dosage form bulk manufacturing [5].
11. **Faster Production:** It allows for easier and faster product manufacturing. This benefit of 3D printing technology can assist designers and professionals in making better decisions when choosing a better manufacturing process and delivering excellent results. [6]

12. **Infinite Shapes and Geometry:** Traditional production methods rely on moulds and cutting techniques to develop desired shapes. With this technology, creating geometrically complicated shapes can be difficult and costly. This technology is taken on by 3D printing. [6]
13. In the event of multi-drug therapy with multiple dose regimens, treatment can be tailored to increase patient adherence. [8]
14. The capacity to control the release of active ingredients permits the drug's action to be delayed or accelerated, hence increasing the tablet's effectiveness. [19]
15. The increased the availability of pharmaceuticals that can be obtained with a doctor's prescription from any pharmacy with a 3D printer. [19]
16. Using a 3D printer to make tablets removes the chance of mixing medications or accidentally taking another patient's tablet. [19]
17. A 3D printer is the only piece of equipment necessary for drug manufacturing. As a result, each local region might have its own mini-factory for tablet production. These printers can be used in military hospitals and even deployed on space missions. This could aid patients in receiving proper treatments even in the event of a pandemic, natural disaster, or other unusual circumstances. [19]

Disadvantages

1. The fundamental shortcoming of 3DP is that it only evaluates the printed structure in its initial condition, which is static and inanimate [4].
2. Only ink with a specific viscosity can be used in inkjet printing to ensure optimum ink flow. [4]
3. When the ink does not have enough self-binding properties or binds with other printer elements, the resulting formulation does not have the appropriate hardness. [4]
4. Due to ink binding with other printer materials, the rate of medication release may be impacted. [4]
5. Size and raw material restrictions, as well as high printer costs [16]
6. Nozzle issues, such as the halting of the print head, pose a significant challenge, as it has an impact on the final product's structure. [8]
7. Another major hurdle is powder printing clogging. [8]
8. Modifications to the final structure due to mechanical stress, storage environment adaptations, and ink formulation effects are possible. [8]
9. Printer-related variables and their impact on print quality and cost. [8]

Techniques [1]

1. Inkjet Printing Method

a) Continuous Inkjet Printer

b) Drop-on-Demand Inkjet Printer

- Thermal Inkjet Printer (TIJ)
- Piezoelectric Inkjet printer (PIJ)

2. Binder Jet Printing
3. Fused Deposition Modeling (FDM)
4. Selective Laser Sintering (SLS)
5. Stereo Lithography (SLA)
6. Pressure Assisted Microsyringe (PAM)

1. Inkjet Printing Method

Inkjet printing, in general, refers to systems that use pattern-generating equipment to control and deposit small liquid drops on a substrate digitally. In pharmaceuticals, adequate drug mixes with appropriate excipients (known as ink) are deposited as minute droplets on a suitable substrate in a layer-wise manner. The two main inkjet printing platforms are continuous inkjet printing (CIJ) and drop on demand (DoD).

a) Continuous Inkjet Printer

Continuous inkjet printers, as the name implies, constantly discharge a spray of liquid droplets onto a substrate, even when the droplets aren't essential. A pressure wave is delivered into the ink stream, which enables the ink to split up into uniformly sized droplets due to nozzle vibration, and then ejects the droplets out the nozzle. This technology wastes ink since it ejects droplets in a continuous stream. High-speed continuous droplet creation, which prevents nozzle clogging, is one of the advantages of this printing process. Low-resolution and high-maintenance costs are both disadvantages.

b) Drop-on-Demand Inkjet Printer

Drops of liquid are expelled from the print head in these printers when a trigger signal is received, and the drops are deposited onto a substrate. This printer has a significant number of nozzles (100–1000), although specialized print heads only have one. Drop-on-demand inkjet printers feature kinetic energy obtained from sources close to each nozzle and placed within the print head, as opposed to continuous inkjet printers, which eject droplets owing to external pressure. This technique is simple to use, provides high precision, and is inexpensive. It has the flexibility to deposit small, controllable drops with high placement accuracy. It also helps to reduce drug waste. Based on the type of print head, drop-on-demand inkjet printers are further divided into thermal inkjet and piezoelectric inkjet printers. On the basis of the substrate on which the print head deposits drops, it is also characterized as drop-on-drop or drop-on-solid.

- **Thermal Inkjet Printer (TIJ)**

The utilization of thermal energy to release droplets, which then exit the nozzle, is the trigger mechanism here. The print heads have resistors integrated in them that are in direct contact with the fluid (ink) and produce heat when an electric current is inducted. The heat causes a bubble to form within the volatile fluid, which expands and ejects a little amount of fluid from the nozzle, generating a droplet (Fig.1a). The use of high temperatures (200–300°C) for the resistor, which could contribute to the breakdown of thermo labile active substances, is the technique's principal restriction.

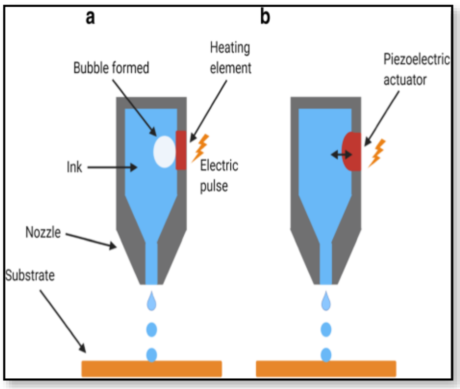

Figure1. Schematic of Inkjet Print head a. Thermal b. Piezoelectric

- **Piezoelectric inkjet printer (PIJ)**

A piezoelectric element or actuator, which changes shape in reaction to an electric voltage, is used in this technology. This creates a force that causes the fluid (ink) to be ejected from the nozzle. The nozzle is reloaded with fluid and ready to be activated once the element has returned to its original shape (Fig.1b). Pharmaceutical printing featured another unique technology termed "valve jet" or "electromagnetic" printing, which was based on small solenoid valves. As compared to a thermal inkjet printer (TIJ) or a piezoelectric inkjet printer (PIJ), this has the advantage of being more stable and having larger orifice diameters, which will aid in producing coarser suspensions. To eject droplets at high frequencies, a glass inkjet tool was designed. Because glass is inert, it would be ideal for medicinal uses. Combining inkjet technology with UV photo-initiation can take it to the next level. In the inkjet printing industry, UV curing has been utilized to harden materials quickly on demand.

2. Binder Jet Printing

Inkjet printing technology is used in this process, which is also known as drop-on-powder. Thermal or piezoelectric print heads are available for binder jet printers. It's made up of a powder bed that's layered together. By moving along an x-y axis, a printer nozzle containing the binder (and/or drug) fluid jets the liquid onto the loose powder bed. The liquid drops dampen the powder, which causes the coating to thicken and solidify. Powder solidification takes place either through the formation of binder bridges or through particle dissolution and re-crystallization. The fabrication platform then falls along the z-axis, while the powder delivery platform rises up. The powder layer is then moved from the bed to the top of the previously bound layer by a roller. This method is repeated several times until the 3D object is complete (Fig.2). The object is then taken from the powder bed, along with any unattached powder. To eliminate any remaining volatile solvent, thermal sintering is commonly utilized. Spritam was developed using the zip dose technology and the TheriForm method, which is a unique micro fabrication process used to produce dosage forms layer by layer, one layer at a time, based on binder jetting.

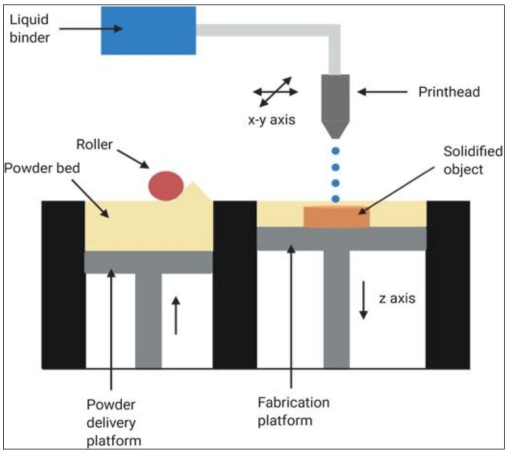

Figure2. Schematic of Binder Jet Printer

3. Fused Deposition Modeling (FDM)

The most widely used 3D printing technology is fused deposition modelling (FDM), often known as fused filament fabrication. Thermoplastic drug–loaded polymeric filaments are introduced into the printer after development and are melted at a specified temperature before being extruded via the nozzle. The initial layer of the product is created by moving the print head in a rastor platform and unloading the extruded filament onto the printer platform. After that, successive layers are deposited by lowering the platform to make way for the next layer. The filaments cool down and adhere to the layer before them. To create the final 3D object, this method is repeated (Fig. 3).In most printers, the print head temperature may be adjusted, allowing the use of various polymers and polymer blends. The medication is integrated into the polymer along with numerous excipients in the hot melt extrusion (HME) process, which produces FDM filaments. This method employs a screw-based extrusion mechanism in a barrel that is operated by a motor and melts the mixture using heat and pressure before being allowed to cool. This liquid then hardens to form the filament that will be used as an FDM feed. The cost-effectiveness, printing accuracy, guaranteed quality parameters, and incorporation of HME are all reasons for FDM's widespread application in pharmaceuticals. The study focused on direct powder 3D printing (DPP), which is a one-step FDM procedure that does not use HME. The powder mixtures were heated and successfully printed to manufacture tablets with a honeycomb design after being loaded into a stainless-steel extrusion cartridge.

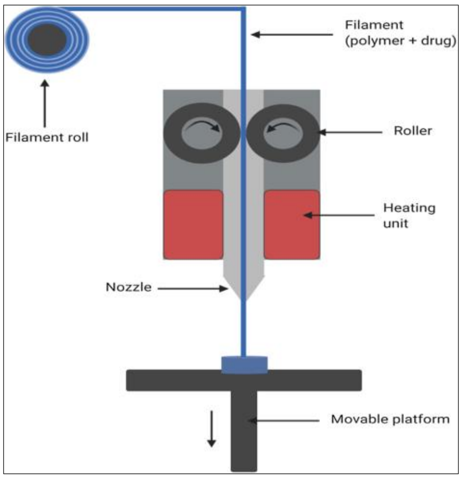

Figure3. Schematic of Fused Deposition Modeling

4. Selective Laser Sintering (SLS)

Selective laser sintering uses laser energy to heat and fuse powder particles, resulting in a solidified 3D product. The spreading platform, powder bed, and laser system are the 3 essential components. The powder is dispersed evenly on the platform by the spreading mechanism, and the surface is evened using a roller blade. The laser system's scanning pattern, which moves in a 2D plane, is predetermined depending on the finalized product's qualities. To create fusion by melting with laser, the material is heated to a temperature below its melting point, and the height of the bed is adjusted to centre laser on the recently formed surface. During the procedure, the loose powder on the platform offers stability. The powder bed is lowered by one layer each time, and the next layer is deposited and fused. This is repeated to create the finished 3D printed object, which is manually or with a sieve retrieved from the loose powder after cooling inside the printer (Fig.4). It's a one-step, quick production method that doesn't require any solvents. Due to the laser precision, it also makes high-resolution objects.

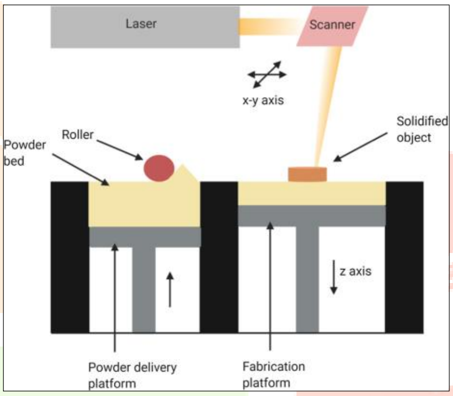

Figure4. Schematic of Selective Laser Sintering

5. Stereo Lithography (SLA)

Stereo lithography is based on the photo polymerization of liquid resin using ultraviolet light to harden it. The UV source can be positioned below the printer and the moving platform may be situated above, or the UV source can be situated above and the platform can be situated below. The initial layer is photo-cured and adheres to the building platform after being traced by the laser in the x and y axes driven by scanning mirrors. The platform then slides across the z-axis to the extent that each layer's breadth allows (moved down in case of bottom-up approach and elevated in case of top-down approach). The liquid resin is then redistributed above the previously hardened layer to complete the hardening process, and the process is repeated to complete the 3D item (Fig. 5). After that, the piece is cleaned with alcohol to remove any remaining resin. To reinforce the object, post-curing with a UV oven might be used. In order to perform photo-cross-linking, the materials employed in SLA must have photo-curable properties. High resolution and reduced thermal stress are two advantages of this printing method.

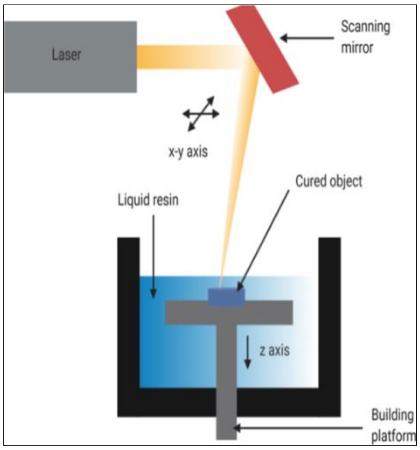

Figure5. Schematic of Stereo Lithography

6. Pressure Assisted Microsyringe (PAM)

A pressure-assisted microsyringe uses a syringe-based head to feed semi-solid material into which the material is extruded continuously, layer by layer, to create a 3D printed item (Fig. 6). A mechanical, pneumatic, or solenoid piston can be used for extrusion. A sufficient blend of polymer, solvent, and extra essential excipients with printing qualities make up the semi-solid mixture. Because solvents are used in the printing process, drying afterward is critical to avoid shrinking or deformation of the final product. The printed object may also collapse if the deposited layer is not strong enough to resist the weight of the subsequent layers. The avoidance of high heat is the key benefit.

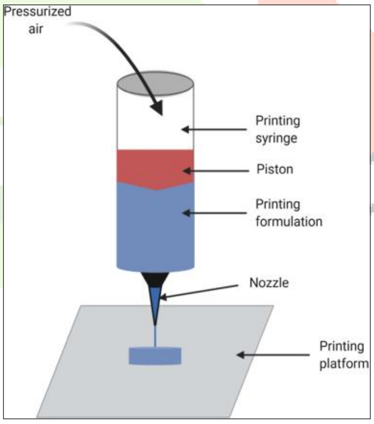

Figure6. Schematic of Pressure-Assisted Microsyringe

Application of 3D Printing

A. Medical Application of 3D Printing

1. Bioprinting of Tissues and Organs

The failure of organs and tissues as a result of accidents, congenital flaws, ageing, and other factors is a serious medical condition, and the current remedy is organ transplantation from deceased or living donors. However, only a few people are fortunate enough to obtain organs, while the others perish as a result of a lack of donors. Furthermore, organ transplant operations are so costly that they are out of reach for most people. Another concern with transplant surgery is the difficulty in finding tissue match donors. Stem cells are separated, mixed with growth factor, and then multiplied in the laboratory in the conventional practice of tissue engineering from a tiny tissue sample. The cells are then implanted onto scaffolds, which promote cell proliferation and differentiation into a functioning tissue. Additional advantages of 3D bioprinting over traditional tissue engineering include accurate cell placement, digitally controlled speed, drop volume, resolution, cell concentration, and printed cell diameter.

Hydrogels are regarded to be the ideal substance for constructing soft tissues out of all the possibilities. Organ printing is undoubtedly still in its early stages of development, but various studies have provided proof of concept. Using 3D printers, scientists have created an artificial ear, cartilage and bone, and heart valve. To create an artificial liver, Wang et al. used 3D bioprinting technology to implant different cells within several biocompatible hydrogels. [4]

2. **Anatomical Models for Surgical Preparations**

Anatomical study models are frequently created using 3D printing. It can be used as a hard copy of the scanned data set, containing visual and tactile information and documentation for visualization, diagnostic, therapeutic, and educational reasons. Because of the variances in individual and complicated human anatomy, knowledge about patient specific anatomy is required prior to medical surgery in order to have successful medical treatments. 3D printed models have shown to be quite useful in this regard, making them an essential tool for surgeries. [4]

3. **Customized Implants and Prosthetics**

Implants and prostheses of any shape can be developed with the help of MRI, CT scans, and X-rays, as well as their translation into.stl 3D print files. Standard and sophisticated surgical implants, as well as prosthetic limbs, can be developed in as little as 24 hours. So far, spinal dental and hip implants have been manufactured, but their certification is a lengthy procedure. [6, 7]

4. **Medical and Dental Products**, such as hearing aids, orthotic shoe insoles, customized prosthetics, and one-of-a-kind implants for patients with ailments including osteoarthritis, osteoporosis, and cancer, as well as accident and trauma victims. 3D printed surgical guides for specific surgeries are another new application that is helping surgeons and patients heal faster. Skin, bone, tissue, medications, and even human organs are all being manufactured using 3D printing technology. [7]

B. Pharmaceutical Application in 3D Printing

1. **Tablets:** Tablets are a popular form of solid dose. The potential of 3DP technologies in pharmaceutical manufacture has been thoroughly investigated using tablets. Tablets manufactured using 3DP technologies can be divided into two categories: single API tablets and multiple API tablets. 3DP technology was used

to create basic rapid release (IR) tablets containing a single API, as well as polypills, which contain many APIs in a single tablet.

2. **Capsule:** A capsule is a dosage form in which the drug is enclosed in a hard or soft shell. Capsules are available in a variety of sizes to enclose the needed amount of medicine, which might be in the form of powder, granules, solution, emulsion, or other formulations. The 3D printing approach was successfully used to manufacture an erodible capsule with different sizes and thicknesses for pulsatile release of diverse medication compositions. It can be filled with powders, pellets, solutions, dispersions, and other formulations, among other solid and liquid dosage forms.

3. **Microneedles:** Microneedles are a kind of transdermal drug delivery system that uses an array of micron-sized needles on the surface of a matrix to improve biologically active molecules' skin penetration. Because of their nanoscale, microneedles may be more successful at delivering macromolecules through the skin than standard patches. Recent advancements in high-resolution 3DP techniques for creating microscopic and tiny structures have accelerated the use of 3DP in microneedle manufacture.

4. **Personalized Drug Dosing:** The goal of drug development should be to increase therapeutic efficacy while minimizing the risk of adverse reactions, which can be accomplished by fabricating customized pharmaceuticals utilizing 3D printing. Oral tablets are produced by blending, milling, and dry and wet granulation of powder ingredients, which are then compressed to form tablets. Due to its ease of preparation, patient compliance, and precise dosing, as well as the fact that they are painless, tablets are still the most preferred dose forms. If adequate standards are not followed in the traditional method of tablet preparation, drugs can readily degrade, resulting in a change in therapeutic value of the final product. Furthermore, conventional methods cannot be used to create customized dosage forms with long-term stability, new drug release profiles, and complex geometries. Drugs with a narrow therapeutic index can be easily prepared using 3D printing, and the patient's pharmacogenetic profile, as well as other factors such as age, race, and gender, can be used to determine the best dosage.

   Another significant result of 3D printing is the ability to create entirely new formulations, such as pills that contain multiple active pharmaceutical ingredients or are delivered as multi-reservoir printed tablets.

5. **Complex Drug Release Profile**

   A straight forward drug release profile is observed in most common compressed dosage forms, which is a homogeneous mixture of active components. A sophisticated drug release profile is found in 3D printed dosage forms, which enable manufacturing of complicated geometries that are porous and loaded with numerous medicines throughout, surrounded by barrier layers that modify release.

6. Personalized Medicine

Some patients respond to the same medications in multiple aspects. 3DP could assist a doctor or pharmacist in determining the best medicine dose for a patient based on their age and gender. It also enables the creation of a single pill that contains layers of numerous diseases that patients require for therapy. 3D printing promotes the integration of medication tailored to the specific needs of patients. Because the range of doses in pediatrics might vary, this strategy can be simply implemented. Similarly, the shape of the dose form can be modified for individuals who have difficulty swallowing. [9]

7. Develop Complicated Forms

3DP promotes the integration of complex structures with precise quantities of drug or API, even as low as 10-12 mole tablets, minimizing the negative effects associated with large doses. In comparison to traditional methods, 3D printing allows for the creation of complex shapes with ease. Similarly, various shapes and sizes result in a variety of release profiles. [9]

8. Integrated with Health-Care Network.

Physicians and pharmacists can customize the next dose or drug combination based on the needs of the patient. Because 3D printers can be operated remotely, 3D printing is becoming more accessible to patients. As a result, patient compliance improves, and clinical response time to patient needs is reduced. [9]

9. Accelerated Disintegration

In terms of disintegration, 3D printing differs significantly from powder compression. Both the traditional and modern methods have distinctive patterns of powder aggregation. Powder binding strength is higher in the periphery and lowers in the center in 3D printing, resulting in rapid tablet disintegration. [9]

C. 3D Printing in Various Diseases

1. Cancer

Cancer is a disease characterized by abnormal and uncontrolled cell proliferation that can invade other tissues and spread to other parts of the body via the systemic circulation and lymphatic system. The development of in vitro models to study tumour development and spread has been made possible because to advances in 3D printing technology. It's very beneficial in cell microenvironment engineering since it enables for fine spatial control of cell structure and biomolecule insertion. It can simulate tissues or organs by including diverse cell types, polymers, vasculature, and micro-channels in addition to the fundamental structure.

2. Cardiovascular Diseases

These are a class of heart and vascular problems that are difficult to treat and control. Due to the difficulty to represent real-size structures in 3D, diagnosis and therapy have generally relied on 2D model Magnetic Resonance Imaging (MRI), angiography, and echocardiography. The generated 3D replica model assists in a detailed understanding of the cardiac anatomy and pathophysiology and appropriately plan therapy with a high degree of precision, thanks to the large amount of data collected from imaging techniques.

3. Diabetes

Diabetes is a metabolic disorder defined by higher-than-normal blood glucose levels (normal pre-prandial: 72–108 mg/dl and post-prandial: 140 mg/dl) caused by insufficient insulin production or inability to utilize the insulin produced. The process of 3D printing has been widely used in the development of diabetes treatment techniques & has been used to design major issues such as the production of insulin-producing islet cells and a customized dose of medications.

D. Food Industry

There is a growing demand for the development of personalized food for daily nutritional demands, which require a particular amount of nutrients by decreasing superfluous components and increasing the presence of good substances. However, the production of customized foods requires a lot of attention to detail and creativity, which is where 3D-food printing comes in. Food layer manufacturing, commonly known as 3D-food printing, is a method of fabricating food by layering consecutive layers obtained directly from computer-aided design data. Specific materials can be blended and processed into numerous complicated structures and shapes utilizing 3D printing technology. Sugar, chocolate, pureed foods, and flat foods like pasta, pizza, and crackers can all be combined to make new foods with sophisticated and attractive shapes and designs. 3D printing is a low-cost, high-energy-efficiency food manufacturing technique that is also eco-friendly and has good quality control. Because it creates a new method for food modification and can react to individual preferences and demands, 3D-food printing can be healthful and beneficial to humans. [2]

Perspectives and Challenges:

If 3DP is refined and combined with cutting-edge technology, it is expected to be the most efficient approach. When large and irregular forms are orally supplied, we anticipate that adopting this technology will result in worse patient compliance. Reduce unpredictability in scaling up and rejecting batches that do not meet specifications, resulting in increased effectiveness and lower costs. Biomolecules, rather than regular chemical entities, are used in personalized medications, which are more responsive to solvent, temperature, and agitation, and for which 3DP technologies could be of great importance. It is difficult to obtain impurity-free substances within specified limits. [15]

Conclusion

The use of 3D printing for advanced drug delivery is becoming more popular. Personalized and tailored medicines are built-in to this technology. Furthermore, it has the potential to revolutionize traditional pharmacy practices by allowing patients' prescriptions to be really personalized. It also allows for accurate dose, shape, and size control in the creation of dosage forms. In the not-too-distant future, 3D printing is anticipated to supplement traditional manufacturing techniques for pharmaceutical dosage forms. It has been illustrated that the use of 3D printing for the elaboration and distribution of controlled drugs plays an important role in the current pharmaceutical industry due to its versatility, speed of production, and precision, considering that drugs can be designed according to the patient's needs.It is believed that 3D printing will change pharmaceutical formulation manufacturing processes in the present era, improving both safety and efficacy. Then, in a smart future with tailored medicine, the healthcare system might be transformed. Despite the prevalence of possibilities and adaptability, 3D printing is expected to supplement traditional pharmaceutical dosage form manufacturing techniques in the near future.

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