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Review Article

3-D Printing in Pharmacy

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ABSTRACT

The pharmaceutical sector undergo a significant transformation becausethree-dimensional printing technology, which offers more tailored and effective medicine delivery options. Customized dosage forms based on age, weight, and medical conditions can be printed using 3D printing to improve safety and efficacy for individual. With this, tablets and capsules with a variety of pharmaceutically active ingredients can be produced in distinctive forms and sizes. In addition, 3D printing makes it easier to create intricate dosage forms with precise release profiles, which eventually enhances therapeutic results and reduces adverse effects. Despite its use, some problems with material science, regulatory compliance, and quality assurance occurs. To ensure the safety and efficacy of 3D printed dosage forms, more investigation is needed to develop guidelines.3D printing technologyenables to achieve high precision, accuracy, and medication consistency has a dramatic impact on the pharmacy sector. It opens up new possibilities for enhanced drug delivery systems, research and development prospects.

INTRODUCTION

Healthcare is only one of the many sectors that 3D printing technology has transformed in recent years. Three-dimensional things can be produced via additive manufacturing, generally known as 3D printing. There are several uses for this technology in the pharmacy industry. We may design complicated buildings using 3D printing to suit our demands. This technology may enhance patient outcomes by enhancing medicine delivery, raising patient compliance, and other aspects of pharmacy practise. Despite the potential advantages of 3D printing, there are still barriers to its adoption in the pharmaceutical sector, such as technological constraints, legal obstacles, and financial concerns. The pros and downsides of 3D printing in pharmacy should be carefully considered as technology develops and becomes more widely available. This review article is to offer a thorough overview of 3D printing

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technology in pharmacy, including its background, present uses, potential, and difficulties.

Background Information On 3d Printing

A rapidly evolving technology called three-dimensional (3D) printing enables the construction of intricate three-dimensional structures by layering material. The fabrication of personalised medical implants, prostheses, and drug delivery systems is one of the many industries that 3D printing has transformed, including healthcare. By enabling the development of more individualised and customised solutions to address each patient's particular needs, the technology offers the potential to enhance patient outcomes.

Chuck Hull developed the first 3D printer in 1986 while using stereolithography to make a little plastic cup. Since then, technology has grown quickly, and today, a wide variety of 3D printers are available, each with unique advantages and disadvantages. The most common types of 3D printers in use today are fused deposition modelling (FDM), stereolithography (SLA), and selective laser sintering (SLS)[1].

The production and delivery of pharmaceuticals could be completely transformed by utilising 3D printing. Complex dosage forms such as multi-layer tablets, individualised drug delivery systems, and drug-eluting implants can be produced via 3D printing[2].In order to develop and test new drugs, the technique can also be utilised to produce anatomically correct models of organs and tissues.

Using 3D printing in the pharmaceutical company comes with challenges as well., though. Since usage of 3D printing for medicine manufacture is still a relatively new and untested area, regulatory issues are one of the biggest challenges. The use of specialised software and materials, as well as the constrained print size and speed, are other technological restrictions on 3D printing[3].

3D printing is building a three-dimensional object from a CAD model or digital 3D model.Murray Leinster first proposed 3D printing in 1945; David E. H. Jones built on this in 1974. Charles "Chuck" Hull developed the first 3D printing method, stereolithography, in 1984.Since then, 3D printing technology has advanced significantly and is now applied in entertainment, automotive, aerospace, and healthcare among other industries.Among the several methods used in 3D printing nowadays are powder bed fusion, material jetting, binder jetting, vat photopolymerization, and directed energy deposition[4].Different materials are used based on the 3D printing technique being applied. Among the common materials are ceramics, composites, metals like titanium and stainless steel and polymers like ABS (Acrylonitrile Butadiene Styrene) and PLA (Polylactic Acid), even food items like chocolate.

3D printing in the pharmaceutical industry:

Individualized Healthcare: The creation of tailored medicine is one of the key uses of 3D printing in pharmacy. To meet the unique needs of each patient, customised medicine delivery systems can be made utilising 3D printing. For example, researchers have used 3D printing to create personalized tablets that have different shapes and sizes, as well as varying release rates, to optimize drug delivery[5].

Novel Drug Delivery Systems: Using 3D printing lets one design new drug delivery systems that go beyond some of the limitations of conventional drug delivery techniques. One example is 3D-printed microneedles developed by scientists that can be used to administer medications through the skin, so improving patient comfort and lowering the demand for injections[6].

Medical Implants:A patient's unique anatomy can be used to create specialised medical implants using 3D printing. This can improve the implant's effectiveness and reduce the likelihood of complications. For instance, spinal implants that are made specifically for a patient's spine have been produced via 3D printing[7].

Tissue Engineering: 3D printing allows three-dimensional scaffolds that can help new tissue development to be created.It can be used to rejuvenate diseased or harmed skin, bone, or cartilage. For instance, researchers have developed scaffolds for bone regeneration using 3D printing[8].

Drug Screening: Three-dimensional structures can be produced via 3D printing and utilised for drug testing. This can decrease the necessity for animal testing and increase the accuracy of drug testing. For example, researchers have used 3D printing to create liver tissues for drug screening[9].

Education and Training: Models of pharmaceutical substances or medical equipment can be made using 3D printing for instruction and training. This can aid in the better understanding of difficult ideas or processes by students and medical professionals. For instance, molecular models have been produced using 3D printing for educational purposes[10].

Quality Control: For quality control purposes, 3D printing can produce accurate representations of drug ingredients or medical equipment. This can aid in locating flaws or departures from the intended design. For exampleThird-dimensional printing has been applied to create quality control models for drug capsules[11].

Rapid Prototyping: Rapid prototyping of new pharmaceutical substances or medical equipment is made possible by 3D printing. This can cut costs and expedite the development process. For instance, 3D printing has been utilised to construct inhaler prototypes[12].

Intellectual Property: Models of pharmaceutical substances or medical devices can be produced using 3D printing for patent reasons. This could aid in defending intellectual property and preventing copying. For instance, models of medical gadgets have been produced via 3D printing for patent applications[13].

Drug Formulation: Drug formulations with enhanced solubility, stability, or bioavailability can be produced using 3D printing. This could raise the safety and efficacy of the medicine. For poorly soluble drugs, for instance, researchers have produced solid dispersion formulations using 3D printing[14].

The pharmaceutical manufacturing sector could be completely transformed by 3D printing.Customised dosage forms, unique drugs, and medication delivery systems can all be produced from it[15]. Currently under research for fused deposition modeling (FDM), inkjet-based, inkjet powder-based, selective laser sintering (SLS), and stereolithography (SLA) is 3D printing usage in pharmaceuticals.In 2015 the US Food and Drug Authority (FDA) approved the first 3D-printed pill.Drug delivery systems for progesterone, pseudoephedrine, and ibuprofen hydrogels among other 3D-printed medical products have lately hit the market.Apart from its possible applications in the manufacturing of medications, 3D printing can also help to simplify difficult oral medicine regimens.Still, efficient pharmacy counseling by pharmacists is absolutely essential for the drug distribution process to enable patients to become more health-conscious[16].The capacity of 3D printing to enable decentralised and customised manufacturing of treatments has overall the power to revolutionise the manufacturing of pharmaceuticals.

Purpose of 3D printing:

3D printing in the pharmacy serves to offer creative answers to enhance tissue engineering, medicinal equipment, and drug delivery systems. Personalized medication delivery, new drug delivery systems, medical implants, tissue engineering, teaching and training, quality control, fast prototyping, intellectual property, and drug formulation are just a few possible uses for 3D printing in the pharmaceutical sector[17].

By applying 3D printing, three-dimensional solid objects begin with an electronic file.It allows for the design and printing of more intricate designs than conventional manufacturing procedures and is utilised for both professional and recreational reasons. With more local service providers providing outsourcing services for industrial operations, 3-D printing is increasingly accessible.Among the advantages of 3-D printing are its capacity to create "one-of- a-kind, reasonably cheap designs that are "one-of- a-kind," a reduction in the time and cost of prototyping for companies, and its ability to create complex shapes with less material than conventional manufacturing methods.

Additionally, 3D printing enables auto enthusiasts to modify their automobiles or restore classic cars with out-of-production parts. The fact that pieces can delaminate under certain circumstances because they are produced layer by layer is one of 3D printing's drawbacks, along with the possibility of mistakes if the software programming is not done properly.

History of 3D printing:

The beginnings of 3D printing technology might be found in the 1980s technique stereolithography developed by Chuck Hull[18].Stereolithography creates three-dimensional objects by layer-by-layer solidification of a liquid resin under a laser. This method assisted many of the present 3D printing technologies to be developed. Since then, 3D printing technology has kept developing and new materials and techniques have been developed. Designed in the 1990s, fused deposition modeling (FDM) uses a heated nozzle to extrude a plastic filament layer by layer to build a three-dimensional object [19]. This approach is nowadays used in many different fields. Created in the 2000s, inkjet-based 3D printing marks still another major development in the field of 3D printing. This method creates a three-dimensional object by layer by layer dropping tiny material droplets onto a substrate using a printhead[20].As 3D printing advances now, new materials and techniques are being developed. Modern technology finds application in manufacturing, engineering, healthcare, and education among other sectors. Though a rather recent technology, 3D printing has a rich and long history[31]. Dr. Hideo Kodama developed the first 3D printer in 1981 by designing a machine capable of layer by layer manufacturing of parts using a resin whose polymerization could be achieved by UV light. New additive manufacturing technologies brought about notable expansion in the 3-D printing sector in the 1990s. Dr. Adrian Bowyer started the RepRap Project in 2005, which turned out to be a driver of commercial 3D printing development. Murray Leinster first detailed the overall idea and technique to be applied in 3D-printing in his 1945 short story Things Pass By. David E. H. Jones first introduced 3D printing in his regular column Ariadne in the journal New Scientist in 1974.Charles "Chuck" Hull invented stereolithography, a printing method whereby liquid resin layer by layer is cured or solidified using UV light to produce a 3D object[5,32], so launching modern 3D printing as we know it today. Over 200 early 3D printing patents expired between 2002 and 2014, so opening the field for more reasonably priced consumer and hobbyist printers. Common 3D printing techniques are

FDM (Fused Deposition Modelling), SLA (Stereolithography), SLS (Selective Laser Sintering), DLP (Digital Light Processing) and PolyJet (PolyJet Matrix). 3D printing originated in topography and photo-sculpture as early as 1860 when French artist François Willeme registered a method for photo-sculpturing. During this process, the subject is positioned in a camera obscura and their image is projected onto a plaster or wax object subsequently carved into form[5,33].

Earliest development of 3-D printing:

At the middle of the 19s, Charles W.Hull created a technique he named "stereolithography," which is when 3D printing first began to take shape[18].Hull is frequently recognised as the creator of 3D printing, and his business, 3D Systems, was the first to make the technology widely available. To produce 3D things from digital models, a process known as photopolymerization is used in stereolithography. Under this technique, a liquid photopolymer is subjected to a the pattern of light that layer by layer hardens the material layer, creating a solid object[21]. Following years produced other 3-D printing techniques including fused deposition modeling and selective laser sintering. These technologies produced 3D objects using various materials and techniques, but they were all based on the same basic principle of layering up an item[22]. In general, the early development of 3D printing was motivated by a desire to enhance production procedures and make the creation of prototypes and new items simpler and faster. The technology has developed new uses across a variety of sectors, including as healthcare, aircraft, and education.Dr.Hideo Kodama produced the first fast prototyping machines in 1981, building pieces layer by layer out of a resin that could be polymerized by UV light. This was the beginning of 3D printing. He applied for the technology's patent in 1986, and in 1988 he established the 3D Systems Corporation.Fused Deposition Modeling (FDM) was first patented by Scott Crump in 1992, and between 1993 and 1999, the major players in the 3D printing business created a large number of 3D printers for both professionals and laypeople. A larger audience was introduced to 3D printing in 2008 because to the growth of open-source projects like the RepRap Project. This led to the growth of commercial 3D printers and contributed to their current widespread use.

Advancement in 3d printing:

Multi-Material 3D Printing: The capacity to manufacture items using various materials is the most important developments in 3D printing technology. Printing with many materials enables the creation of things with a variety of hues, textures, and compositions. This technique is helpful in fields like advanced engineering and prosthetics[23].

4D Printing:3D-printed things can alter in shape or behaviour over time thanks to the emerging technology of 4D printing. Self-transforming structures are produced by this technique using intelligent materials that change in response to environmental factors like heat or moisture[24].

Metal 3D Printing: Intricate metal parts for the aerospace, automotive, and medical industries may now be produced using metal 3D printing, which has lately become more widely available and more reasonably priced. The quality, accuracy, and speed of metal printing have all improved because to developments in 3D metal printing technology[25].

Continuous 3D Printing: With 3D printing, large objects may be generated continuously, reducing the need for post-processing and increasing productivity. Utilizing this technology, structures such as buildings, bridges, and even boats can be made[26].

Bioprinting: The method of using 3D printing technology to manufacture living tissues and organs is known as bioprinting. By making it possible to create individualised, useful organs, this technology has the potential to completely transform the area of regenerative medicine[27].

Light-activated 3D Printing: University of California, San Diego researchers have created a 3D printing technique that activates the manufacturing of various materials using light. As a result, the printing process may be controlled more precisely, and intricate geometric structures can be produced[28].

3D Printing with Living Cells: University of California, Berkeley researchers have created a 3D printing method that uses living cells to produce biological tissues that are functional. Using this technique, individuals who require transplants could produce new tissues and organs[29,30].

Continuous 3D Printing of Carbon Fibre Composites: The Massachusetts Institute of Technology has discovered a process for printing carbon fibre composites in continuous 3D. This might result in the creation of strong, lightweight components for use in automotive and aerospace applications[31].

3D Printing with Recycled Plastic: University of Bath researchers have created a 3D printing process that produces new things using recycled plastic. This might contribute to reducing plastic waste and offering a more environmentally friendly method of 3D printing [32].

These are only a few recent examples of 3D printing technology developments. As this field's research advances, we can anticipate seeing new discoveries and applications develop.

Modern developments in 3-D printing technologies allow one to fabricate intricate 3D structures using CAD software or digital photographs. A wide range of industries, including aviation, geoscience, education, and apparel, are currently using it. 3-D printing is used in the medical industry to manufacture sophisticated products and ideas for designs for individual patients[33].Reduced lead times for 3D-printable equipment, integration into maintenance procedures, and cost-effective wide adoption are some possible advantages of 3D printing.There are several businesses, like GE, Lockheed Martin, and Boeing, are utilising 3D printing to increase output, and other businesses are relying on 3D printing vendors to quickly produce necessary goods. Due to 3D printing's extraordinary flexibility, which enables simple product modification and reduces assembly and shipping expenses, it is poised to revolutionise the industrial economy. Furthermore, it can be applied to the quest of performance improvements in sectors like aerospace and automotive.

3D printed drugs:

Drugs can be made in specialised forms and dosages addressing a patient's needs with 3-D printers. The first and only 3D-printed medicine approved by the FDA is Spritam (levetiracetam) from Aprecia Pharmaceuticals.The first 3-D printer for personalised drug manufacturing has been released by Merck KGaA and FabRx recently announced a 3-D printed medicine development and manufacturing alliance with AMCM.

.With Aprecia's ZipDose Technology, 3DP for Pharma technology is at the forefront of personalised medicine, redefining quick melt and creating new possibilities for drug administration [52]. This technology may potentially make it easier to create deadly medications, although this raises questions about safety.

Personalized medicine:

A rapidly developing area called "personalised medicine" tries to tailor medical care to every patient given to their unique genetic background, lifestyle or other qualities. Making patient-specific medical gadgets, implants, and prosthetics using 3-D printing technology is an exciting advancement in personalised medication. 3-D printing technology has the Power to transform tailored medicine by enabling the production of customized medical devices that are customized medication to each patient's unique Propertise and medical needs [34]. In the quickly developing field of personalised drug , medical treatments are tailored to specific individuals based on their genetic make-up, lifestyle, and other particular aspects. Using 3D printing technology to make patient-specific medical gadgets, implants, and prostheses is a fascinating advancement in personalised medicine. According to a study in the journal "Current Opinion in Biomedical Engineering," 3D printing technology has the Power to transform personalised medicine by making it possible to produce medical devices that are specifically designed for each patient's individual anatomy and medical requirements[35]. The creation of prosthetics is another area in customised medicine where 3D printing has showed promise. Traditional prosthetics frequently have poor fit, discomfort, and limited functioning. Using 3D printing, it is possible to create individualised prosthetics that are not only practical and comfortable but also easy to use[36].The development of patient-specific medical devices, implants, and prosthetics made possible by 3D printing technology has the potential to transform personalised medicine. Although the field is still developing, the quick progress being achieved points to a promising future for personalised medicine.The ability to customise pharmaceuticals for specific patients using 3D printing makes it a promising tool in customised medicine[37]. With this technology, polypills—single tablets that combine several different medications—might be produced. Additionally, customised drug delivery systems and dosing regimens can be made via 3D printing. Additionally, the usage of 3D printing in healthcare settings can increase patient compliance and lower the price of drug research[41]. A new area of study called "4D printing" incorporates a fourth dimension of time into the 3D printing process. It relies upon the same principles as 3D printing. It may be likely that 3-D printing may play a significant role in personalised medicine in 15 years, enabling more individualised therapies and better patient results[38].

Use of medical imaging data to create 3D models:

Among medical imaging modalities that offer exact information on human body architecture and disorders are magnetic resonance imaging, computed tomography, and ultrasonic waves.Three-dimensional (3D) Ways of the patient's anatomy can be made using these photos, and these models are particularly helpful in personalised medicine for surgery planning, medical education, and visualisation of intricate anatomical systems. A study that appeared in the Journal of Medical Systems claims that the software programmes Mimics, 3D Slicer, and OsiriX may be used to transform medical imaging data into 3D models. These techniques enable the segmentation of anatomical features from medical images like CT or MRI scans and the production of 3D models which may be used for surgical planning, virtual reality simulations, and other applications[39]. Surgical planning is one application for 3D models derived from medical imaging data that has shown significant potential. These models can be used by surgeons to practise operations and prepare the best strategy for each patient. For instance, a study in the Journal of

Cranio-Maxillofacial Surgery discovered that complex craniofacial procedures may be planned and carried out using 3D models made from CT scans[40]. 3D models made from medical imaging data used for anatomical planning along with medicinal training as well as teaching. Those models can help medical learner and trainees comprehend intricate morphology and pathophysiology of the human body and practise surgical procedures in a virtual setting. It is feasible to create 3-D models from medical imaging data using a variety of software programmes. In personalized treatment, surgical planning, medical education, and the representation of complex anatomical components, these models find application.

Anatomical structures can be represented in three dimensions using medical imaging data[41,42]. The most popular imaging modalities for this purpose are MRI and CT as they produce DICOM data sets that may be used to choose voxels within a dataset relevant to anatomy of interest and construct a 3D volume. The DICOM data can then be utilised to generate 3D models using software like 3DSlicer and other tools.These models can offer useful insights into patient anatomy, assisting surgeons in better comprehending the anatomy of the patient and informing their surgical choices. To understand how 3D models are created and what uses they have in medical practise, the American College of Radiology has also set up a registry that gathers anonymized data on cases of 3D printing.

Creation of drug delivery devices for targeted treatment:

Drug delivery research has recently placed many emphasis on the development of focused drug distribution methods. Targeted drug delivery systems enable drugs to be delivered to exact sites in the body, so reducing the possibility of the drug having negative effects on healthy tissues and increasing their therapeutic efficacy. For 3D printing technology, the development of drug delivery systems for exact therapy has great promise. According to a paper in the journal "Expert Opinion on Drug Delivery," 3D printing can be used to create tailored drug delivery systems fit for the demand of particular patients. By means of these devices, medications can be delivered at a predefined rate or location, so enhancing their efficacy and reducing their side effects risk. A 3D-printed drug delivery tool is a tablet with a set rate of medication release. Printing several layers of the tablet with varying drug or drug combination helps to release the medications under control over time[43,44]. Another example of a 3D-printed drug delivery system is a microneedle patch fit for transdermal treatment. Printed on the patch are microneedles that could be loaded with drugs and readily pierce the skin to reach the bloodstream[45]. Apart from producing customised drug delivery systems, 3D printing technology can be used to make surgical implants covered with drugs to provide localised drug delivery. This approach has been used in orthopaedic surgery to provide continuous release of antibiotics at the site of infection, so lowering the likelihood of systematic adverse effects[46].3D printing technology has the ability to transform drug delivery by allowing the creation of customised medicine delivery devices fit for the demands of particular patients. Though the field is still in its early stages, targeted medicine delivery shows great future.

One can use a new technology known as nano-based drug delivery systems to provide drugs or naturally occurring active compounds to specific body parts[47]. These systems are made to regulate the size, surface characteristics, and release rate of compounds that are pharmaceutically active. They have been applied to enhance the transport of proteins, peptides, and other therapeutic modalities as well as tiny compounds[48]. The use of nano-based drug delivery systems[49]as well as for receptor-targeted administration and controlled transdermal distribution will help both tailored therapy and personalised medicine.They have also been used to improve animal cell treatments; future application of them is expected. Among nano-based drug delivery systems are vesicular DDSs, polymeric nanocarriers, and layer-by- layer built nanodrugs[49].

Drug Delivery Methods:

An indispensable part of modern medicine, medication delivery systems can totally change drug treatment. The ability of 3D printing technology to create intricate and customised constructions with a great degree of accuracy has resulted in a growing application of this technology for the development of drug delivery systems. One use of 3D printing in the pharmaceutical sector is the building of implants for drug delivery.3D printing has let researchers create implants with complex internal structures and geometries that allow controlled drug delivery. The Journal of Controlled Release published one study on 3D printing an implant for local drug administration in the treatment of the brain tumour glioblastoma. The implant shown good biocompatibility in animal tests[50] and has a regulated medication release pattern. Development of microneedle arrays for transdermal medication delivery is another application of 3D printing. Little needles in these arrays can pierce the skin and carry the medication into the bloodstream. 3D printing successfully produced dissolvable microneedles for the transdermal insulin delivery, claims a study in the Journal of Pharmaceutical Sciences[51]. Furthermore possible with 3D printing are drug-loaded tablets and capsules with complex geometries and controlled release profiles. One example is the 3D printing spiral-shaped tablet for continuous release of a medication. Designed to release the medicine over 24 hours, the tablet had decent in vitro drug release kinetics[52].3D printing technology has great promise in the construction of drug delivery systems that can be tailored to the specific requirements of patients. The ability of technology to create complex structures with exact geometries and controlled release patterns opens new directions for medication therapy. 3D printing has become rather popular as a method for manufacturing drug delivery systems due of its possible advantages over conventional approaches[53].3D printing[54,55 allows one to create particular medicine dosage forms with a range of geometries to satisfy the needs of every patient. This method has produced several drug delivery devices including transdermal patches, microneedles, and implants[56]. Apart from that, 3D printing can be applied to create devices including several components, such as actuators and pumps for more advanced medication delivery systems.

Incorporation of drugs into 3D printed devices:

A cutting-edge method of drug distribution that has drew a lot of attention. recently is incorporation of medications into 3D printed devices. In this method, devices that release medications in a targeted and regulated manner are made utilising 3D printing. Here are some instances of how medications can be included in 3D printed gadgets:

Coaxial 3-D printing: Coaxial 3-D printing is a method that includes simultaneously printing two separate materials, such as a polymer and a medication. This method enables exact control of the drug's quantity and placement within the apparatus. For instance, scientists have developed a device for the controlled delivery of the anti-inflammatory medication diclofenac using coaxial 3D printing. Over the course of several weeks, the gadget was able to dispense the medication steadily[29].

Post-printing modification: In this method, 3D printed items are modified after printing to add pharmaceuticals. For instance, a study team developed a polycaprolactone 3D-printed device to administer the anti-cancer medication doxorubicin by covering it with a layer of chitosan that was pre-loaded with the medication.This approach enabled a focused and continuous delivery of the medication to cancer cells[43].

Embedding drugs in the device structure: In this method, the medicine is built into the design of the 3D-printed gadget. This can be accomplished by incorporating the medication into the raw material used for printing. For example, researchers have created a 3D printed gadget that precisely and under control releases the anti-cancer drug cisplatin. The medicine was embedded into a polymer used to print the device, allowing for prolonged release over several days[57]. These techniques show the possibilities of 3D printing for the development of unique, exact, and efficient drug delivery systems. One area of growing interest in the pharmaceutical industry is including drugs into 3D printed goods.[58]. Drug delivery device (DDD) prototypes can now be made via 3D printing, with variable degrees of intricacy and personalization[59]. Changeable drug content and form multi-layered tablets (polypills) from,microneedles or transdermal medication delivery, and tablets with numerous pharmaceuticals and specified release profiles are examples of 3D printed items[15], Providing customised dose formulations for individuals[53].Improved drug dose structures, regulated and tuneable drug release, minimally invasive administration, high-precision dosing, and personalised treatment are several potential uses of 3D printing in pharmacaceutics[59,60]. Before producing pharmaceuticals in 3D printers can be routinely done in pharmacies, further study must be done.

Controlled release of drugs for improved efficacy in 3d printing:

An essential component of medication delivery those tries to increase the effectiveness and safety of pharmaceuticals is controlled drug release. Due to 3D printing technology, it is currently feasible to build drug delivery systems with exact drug release control.Here are some instances of the controlled release of medications via 3D printing: Porous structure design: Porous structures that can contain pharmacological loadings can be made via 3D printing. As the drug molecules diffuse through the pores, the porous structure enables regulated drug release. For instance, scientists have developed porous scaffolds for the controlled release of the antibiotic ciprofloxacin via 3D printing. Over the course of several days, the scaffolds were able to release the medicine steadily.Microsphere incorporation: Devices with drug-loaded microspheres can be made via 3D printing. As the medications deteriorate or dissolve over time, the microspheres offer a regulated release of the medication. For instance, a study team developed a device for the prolonged release of the anti-inflammatory medication dexamethasone using 3D printing. The amount of drug-loaded microspheres used in the device allowed for a sustained release of the medicine over the course of several weeks[61]. Multi-material 3D printing: Devices that release medications under regulated conditions can be made using 3D printing and a variety of materials. For instance, scientists have developed a device that administers the anti-cancer medication doxorubicin using multi-material 3D printing. Two different materials, one of which delivered the medication immediately and the other slowly, were used to print the device. With this strategy, the medicine might be released to cancer cells in a targeted and sustained manner[62]. These examples demonstrate how exact control over drug release can be achieved by means of 3D printing in medicine delivery systems. Especially for conditions requiring long-term treatment, these devices help to increase the safety and effectiveness of drugs.

3D printing has produced customizable medical tools and drug delivery systems to meet special needs. 3D printing can be used to create complex structures for the pills so controlling the release rate of a medicine. Customised dose forms can also be made from it. Moreover, it has been applied to produce multi-layered tablets with various drug release characteristics. For controlled and tuneable drug release, Kyobula created 3D inkjet printing of tablets using specialist complex shapes; Martase developed a new stereolithographic multi-resin 3D printing method[63].Generally, 3D printing technologies have been applied to extend medication delivery systems considering better survivability by means of controlled drug release[64].

Prosthetics and Medical Implants in 3d printing:

The creation of prostheses and medical implants has been transformed by 3D printing. The technique makes it possible to quickly and accurately produce specialised devices that fit the anatomy of the patient. Here are some instances of 3D-printed medical implants and prosthetics:

Prosthetics: Patients with congenital limb deficiencies or amputations can now get prosthetic limbs.. One famous instance is the prosthetic hand created by the e-NABLE community., a global network of volunteers who make 3D printed prosthetics for kids. Due to the prosthetic hand's low cost and adaptability, many children have been able to live better lives.

Dental Implants: Dental implants have also been produced via 3D printing. For instance, scientists have developed bespoke dental implants using 3D printing that are highly accurate and precise. The implants are created using information from the patient's CT scan and printed with biocompatible materials like titanium. The outcome is a personalised implant that is more functional and comfortable for the patient [65].

Orthopaedic implants: 3D printing has also produced orthopaedic implants including hip and knee replacements. By allowing the creation of implants more exactly matching the patient's anatomy, the technology helps to improve the postoperative outcome. Using 3D printing, a research team produced a titanium hip implant for one patient suffering with osteonecrosis. The implant's exact fit for the patient's anatomy produced a positive surgical result[66].

These instances show the 3-D printing's promise for prosthetic and implant manufacture. The technology could improve patients' quality of life as well as help to speed up manufacturing of these devices and cut their price.

Custom implants and prostheses are increasingly being made by use in medicacne using 3- D printing technology. Advantages of 3-D printing include great precision, complex structures, and efficient material use. Numerous implantable medical devices, such as vascular stents, heart valve prosthesis, orthopaedic implants, artificial joints, and more have been made using it[7].Additionally, carbon-based artificial retinas manufactured using 3D-printed implants are being utilised to aid those who have lost their vision. Additionally, 3D-printed jaw implants are being used following tumour resection, and 3D-printed clavicle implants have been successfully put in patients.beacuse of its low cost and capacity to offer patients in need of customised solutions, 3D printing is also being used increasingly frequently for prosthetic limbs. But some have expressed concerns about the robustness of 3D-printed items created by volunteers who contribute their time and expertise to those in need.

Customization of prosthetics and implants in 3d printing:

Customizing is one of the main advantages of 3D printing for prosthesis and medical implants.Here are some instances of how 3D printing has been used to customise implants and prosthetics:

Implants in the skull: Customized cranial implants have been produced via 3-D printing for individuals who have undergone skull operations. These implants can be 3D printed in biocompatible materials like titanium and are created using the patient's CT scan data. Better results are obtained since the implant can be tailored to perfectly fit the patient's anatomy[67].

Maxillofacial implants: Thanks to 3D printing, patients having maxillofacial operations can now get customised implants. Made using patient CT scan data, these implants can be 3D printed in biocompatible materials like titanium. Better outcomes arise since the implant can be customized to precisely match the anatomy of the patient[68].

Prosthetic limbs: Custom prosthetic limbs that precisely suit the patient's remaining limb have been produced via 3D printing. Numerous materials, including ABS, PLA, and nylon, are suitable for 3D printing to create these prosthetic limbs. The prosthetic can be adjusted to satisfy the particular needs for comfort and usefulness[69].These examples highlight how medical implants and prosthesis customizing can be achieved with 3D printing. The ability of the technology to produce devices precisely matching the anatomy of the patient leads to better outcomes and improved quality of life.

3D printing technology allows prosthesis and implant modification to better suit the anatomy and needs of particular patients[70]. This approach has been applied to create patient-specific implants for bone anomalies following the removal of pelvic tumours[71], additionally personalised cutting guidelines for tibial osteotomies[72]. The creation of lightweight, patient-specific solutions for intricate designs that enhance comfort, use, and aesthetics is another application for 3D printing. Additionally, prosthetists can change 3D-printed prostheses using a heat gun to further personalise them for better fit and comfort[73].

Improved patient comfort and reduced complications in 3-d printing:

3D printing can help to lower complications and improve patient comfort in many different medical uses. Here are some examples:

Dental implants: Dental implant implantation surgical guidelines can be made via 3-D printing. These guides can be 3-D printed using biocompatible materials like dental resin and produced from CT scan data of the patient.. Utilizing these guidelines during implant surgery will speed up healing and increase implant placement accuracy, which will improve patient comfort and lower risk of problems.

Prosthetic limbs: Prosthetic sockets that are more comfortable for the patient can be made via 3D printing. These sockets, which may be 3D printed in flexible materials like TPU, can be made to exactly suit the patient's remaining limb. A better fit from the prosthetic socket's personalization can lower the risk of issues like skin irritation and pressure sores[36].

Orthopaedic implants: Made using 3D printing, custom orthopaedic implants can be precisely fit for the patient's anatomy. Using these tailored implants helps to lower the risk of problems including implant loosening and improve the comfort of the patient[74].These examples highlight how 3D printing may improve patient comfort and ease problems in many different medical fields. The ability of the technology to produce devices exactly matching the anatomy of the patient results in better outcomes and an improved quality of life[75].The use of 3D printing in medical operations has improved patient comfort and decreased problems[88]. 3D printed models help doctors understand a patient's exact anatomical structure, so facilitating more exact preoperative planning and reducing risks and consequences.[77].Spatial systems for tissue engineering, as well as implants and other medical equipment, have all been produced using 3D printing. Invasive operations including lumbar punctures, thoracotomies, and central line installation have also been practised on 3D printed models, which can help patients feel more at ease and less anxious. It makes sense and is less expensive to simulate procedures using 3D printed materials than to perform actual procedures[76].

Tissue Engineering in 3-D printing:

The interdisciplinary area of tissue engineering integrates biology, engineering, and medicine to produced biological replacements to preserve or enhance cell function. THE potent technique for manufacturing intricate tissue structures with exact control over geometry, mechanical characteristics, and microarchitecture is 3D printing.

Here are a few instances of current tissue engineering research using 3D printing:

In one study, scientists developed a scaffold for producing human bone tissue using a specialised 3D printer. They used a biodegradable polymer and a ceramic material to create a scaffold that matched the form of real bone.Researchers were able to create functional bone tissue in the lab after seeding the scaffold with bone-forming cells[78]. In another study, scientists employed 3D printing to construct a sophisticated blood artery network inside of real liver tissue. Collagen and alginate were used to print a scaffold, which was subsequently covered in liver and endothelial cells to produce a functional liver tissue. For up to 40 days, the printed liver tissue was able to live and function in the laboratory[79].

In a third study, scientists employed 3D printing to build a scaffold on which a working human heart could be grown. A scaffold made from alginate and gelatin was then covered in heart muscle cells and endothelial cells.. The researchers believe that this technology could one day be utilised to make new hearts for individuals with heart disease because the printed heart tissue was able to contract and pump like a human heart[80].

Tissue engineering relies heavily on 3D printing[81], which enables the creation of intricate constructions employing cells, biocompatible materials, and other supporting elements(96). The characteristics of 3D printed constructions produced from several synthetic and natural materials with cytocompatibility[83] .under focus here areApart from generating tools in the domains of biomaterials and tissue engineering, 3D printing has been applied to create scaffolds for bone tissue engineering. Smart polymers have also been applied in 4D printing[84] to provide tissue engineering uses total control over the design and architecture of the scaffolds.Using 3D printing for tissue engineering purposes still has certain disadvantages. These cover issues with mechanical properties, cell survival, biodegradability, and economic viability. To address these challenges, researchers have developed new bio inks with improved mechanical robustness and structural interconnectivity. Additionally developed are new technologies meant to boost cell viability during 3D printing methods, such laser-assisted bioprinting[82].

Implementing 3D printing in tissue engineering:

One use of 3D printing in tissue engineering is the building of a three-dimensional structure for cartilage tissue engineering. Using a 3D bioprinter, researchers assembled a biodegradable polymer with chondrocytes—the cells that produce cartilage—into a scaffold with a designated form and size. They then successfully produced functional cartilage tissue after growing the scaffold in a bioreactor[85]. Another example is the building of a scaffold to support the expansion of liver tissue. Using a 3D printer, researchers mixed collagen and alginate to create a biodegradable scaffold. Once the scaffold had been seeded with liver cells, the printed liver tissue displayed good vitality and liver-specific capabilities[86].The field of tissue engineering could be totally changed by the capacity of 3D printing to precisely control the composition and properties of scaffolds as well as generate complex, three-dimensional tissue architectures.

3D printing is a hopeful technology for regenerative medicine and tissue engineering. It can enable the creation of complex constructions not financially feasible with traditional methods. 3D printing allows one to create patient-specific scaffolds for tissue design[84] and bioprinted structures with precisely 3D architecture created from live human cells. This technology allows a variety of anatomical structures—including vascularized tissues for use in drug testing and regenerative medicine—to be produced. Customised 3D printing allows a range of vascularized 3D tissues for use in drug testing and regenerative medicine.

Potential for 3D printing to create replacement organs and tissues:

Creating replacement organs and tissues with 3D printing, which is widely accepted and researched in recent years. Several studies on this subject are shown here as examples: In one case, scientists created a tiny, functional liver implant for a mouse using a 3D printer. The implant was developed by the researchers using human liver cells and a biodegradable scaffold material. It was capable of carrying out some of the activities of a natural liver, including removing toxins from the circulation[87].

In a different study, scientists built a biodegradable scaffold for developing heart tissue using a 3D printer. The scaffold was able to sustain the development of working cardiac tissue after being seeded with heart cells. The researchers think that in the future, people with heart disease may receive substitute heart tissue thanks to this technology[79].

In a third study, scientists developed a biodegradable scaffold for generating pancreatic tissue using a 3D printer. The scaffold was able to enable the development of useful pancreatic tissue after being seeded with pancreatic cells. The researchers envision using this technology to produce replacement pancreas tissue for diabetes patients in the future[88].

These findings point to 3D printing's ability to transform organ and tissue replacement by allowing researchers to create complex, three-dimensional tissue constructions with exact control over geometry and purpose.

To address the present organ scarcity, 3-D printing has the potential to revolutionise organ and tissue replacement[89]. A tissue and organ is constructed utilising a bottoms-up method in 3D bioprinting by adding layers one at a time. This method is being applied to produce scaffolds that can assist in the regeneration of damaged tissues, additionally to bio inks for 3D bioprinting of bone, cartilage, skin, and cardiac tissues[90] ·Only one organ has been successfully created in 3D and transplanted into a human to far: the bladder. Scientists are working on building other organs, including kidneys and lungs, using 3D bioprinting techniques though. Usually starting with cells taken from the patient's own body that are placed in a printing chamber and extruded in layers, the process then creates an organ or tissue structure Although it could take up to 10 years before completely functional bioprinted organs can be placed into humans, this method has the potential to save lives by providing an alternative answer for patients awaiting organs or tissues for transplantation.

Future Approaches of 3-D Printing in Pharmacy:

Bioprinting:

The primary objective of the 3D printing subfield called bioprinting is the production of living cells and tissues. The disciplines of medicine and pharmacy could be revolutionized by enabling the design of complex tissue architectures for tissue engineering, disease modeling, and drug screening. Using bioprinting allows functional tissue models that replicate the microenvironment of human tissues to be produced for more exact drug testing and customised treatment.

One of bioprinting's main advantages is its capacity to create tissue architectures with exact control over extracellular matrix elements and spatial distribution of cells. By allowing the development of tissue models more faithfully reflecting the microenvironment of real tissues, this helps more exact drug testing and tailored therapy. Moreover, bioprinting and seeded with cells allows one to create new tissues and organs from tissue engineering scaffolds[91].

Overall, bioprinting has the potential to considerably advance the discipline of pharmacy by allowing the building of scaffolds and working tissue models for tissue engineering, as well as more precise drug testing and tailored therapy. Current bioprinting research is concentrated on enhancing the accuracy and precision of bioprinted structures as well as creating new bioprinting methods and materials for particular uses[92].

The pharmaceutical production sector could undergo thanks to 3D printing, a metamorphosis [88]. It may be possible to produce patient-centred dose forms as well as treatments that are made in a decentralised, customised manner. Personalized splints, patient monitoring, and wound care are all being provided via 3D printing in critical care/ Furthermore under research is the technology's ability to produce customized drugs. Major challenges to the effective implementation of 3D printing in the medical sector still are cost, adaptability, and legal constraints[[12, 94]].Furthermore, technological developments are required even before 3D printing finds increasing application in the medical sector.Though more research is needed to completely grasp its possible uses and challenges, 3D printing shows great promise for the development of medications and medical technologies overall.

Generation of organs and live tissues:

Bioprinting is a fast expanding technique with great potential to transform the field of regenerative medicine by allowing the creation of living tissues and organs. By means of exact layer-by--layer deposition of cells and biomaterials, three-dimensional structures simulating the environment of live tissues are generated by bioprinting [95].

One of the main advantages of bioprinting is its capacity to generate complex tissue architectures with exact control over the spatial distribution of cells and extracellular matrix elements. By allowing the building of tissue models more faithfully reflecting the microenvironment of living tissues, this helps to improve disease modeling and drug screening. Moreover, bioprinting and seeded with cells allow tissue engineering scaffolds to grow fresh tissues and organs.

Bioprinting could greatly advance the field of regenerative medicine by enabling the creation of living tissues and organs for transplantation and other therapeutic uses. Modern bioprinting studies mostly focus on developing new bioprinting techniques and materials for specific purposes as well as improving the accuracy and precision of produced structures.

3D bioprinting, a developing technology in the domains of tissue engineering and regenerative medicine, allows one to build complex biological constructions. Usually referred to as either extrusion, droplet, or laser-based bioprinting, it is a bottoms-up process whereby a tissue or organ is layer by layer constructed[96]. Living tissues and organs[97] produced using 3D bioprinting have found application in organ transplantation, drug testing, and regenerative medicine[110].Using a multi-material 3D bioprinting technique developed by Harvard University Wyss Institute, living human cells are precisely 3D structured to create vascularized tissues. This new approach can be changed to generate various 3D vascularized tissues for drug testing project[98] and regenerative medicine. Other teams of research have also looked at 3D bioprinting of skin, heart, cartilage, and bone tissue using bio inks[90].

Potential for regenerative medicine:

3D printing has the ability to totally revolutionize regenerative medicine by enabling the creation of complex three-dimensional structures that remarkably reflect the surroundings of live tissues. Two such examples are building scaffolds for tissue engineering and direct printing of cells and biomaterials to produce live tissues and organs.

The issue of a lack of donors may be solved, and the danger of immunological rejection could be decreased, by using 3D printing to manufacture tissues and organs that are unique to the patient. This could have substantial effects on how a variety of illnesses and injuries, including as burns, heart disease, and spinal cord injuries, are treated[99].

Current 3D printing for regenerative medicine research is working on accuracy and precision of printed constructions as well as developing new materials and techniques for specific applications. As technology advances, 3D printing could transform the field of regenerative medicine and improve the lives of millions of people all around.

Using 3D bioprinting in regenerative medicine might help to alleviate the organ and tissue scarcity[100].Among the subsectors that would gain from the application of 3D printing technologies including stereolithography (SLA) and 3D bioprinting[101] are bone and neural tissue engineering, the creation of controlled microenvironments, and 3D bioprinting. The success of manufacturing industrial prototypes and surgical tools as well as prosthesis points well for the direction of regenerative medicine [102]. Recent applications of tissue engineering and regenerative medicine have made use of the development of 3D bioprinting technologies[103].

Improved Drug Delivery by 3d printing:

By making it possible to design intricate dosage forms with exact control over the kinetics of drug release, 3D printing has the potential to revolutionise medication delivery. This can call for creating unique dosage forms for every patient as well as advanced multi-drug delivery systems[104].

Among the main advantages of 3D printing in drug delivery is the ability to create complex geometric structures with exact control over the size, shape, and porosity of the dosage form. By ensuring the appropriate amount of medicine is supplied to the appropriate area in the body at the appropriate time, this can enable more effective drug administration and enhance patient outcomes.

Overall, the ability to create more individualised and accurate dose forms made possible by 3D printing has the potential to greatly improve drug administration. The main areas of present research in 3D printing for drug delivery are the development of new materials and techniques for specific applications as well as improving the scalability and commercial feasibility of 3D printed dosage forms.

3D printing is a promising additive manufacturing technique for drug delivery since it helps to produce 3D objects with various drug release properties[105].This technology has been applied to enhance drug delivery by means of tailored dose forms that might meet the requirements of every patient [56].Furthermore developed using it are creative drug delivery techniques including microneedles and transdermal patches[53,106]. Furthermore, 3D printing can be used to rapidly produce medications, so increasing access to them and lowering drug consumption[56].By allowing individualised treatments and more exact control over drug release, 3D printing has the overall ability to revolutionise medicine delivery [55].

3-D printing: targeted and regulated drug release:

3D printing presents the possibility to provide focused and regulated drug release by developing and manufacturing specialized drug delivery devices that release medications at exact times and sites in the body. This can improve patient outcomes, lower side effects, and make medicine distribution more efficient[107]. One advantage of 3D printing is the capacity to create complex and distinctive dosage forms—such as microneedles, implants, and multi-layered tablets—that can precisely and under control drug release. Furthermore overcome with the use of this technology are the restrictions of conventional drug delivery systems including low bioavailability, poor solubility, and dose variability[[108]].

The use of 3D printing for pharmaceutical purposes is under much investigation; efforts to produce new materials, refine printing techniques, and raise technology scalability are among them. As it develops, this technology has the potential to transform drug delivery and raise the efficacy of treatments for many different diseases and disorders.

Using 3D printing in a range of delivery techniques—including oral, topical, rectal and vaginal, parental, and implantable—targeted and controlled medication release systems have been created. 3D printing allows one to create customized organic structures; this is necessary for implants and transdermal drug distribution to control drug release kinetics. Polymers are attractive materials for 3D printed drug delivery[109] because of their special qualities for drug loading, drug release, biocompatibility, and biodegradability.Modulated-release Using a range of 3D printing technologies[53] and temperature-responsive hydrogels—which are then used to create drug delivery systems that release the active ingredient when exposed to a particular temperature—budesonide dosage forms and other controlled release formulations have been developed. Additionally developed using 3D printing[93] and tablets with known drug release patterns including many medications are transdermal medicine delivery systems. The present work presents a fresh concept for manufacturing coating systems in the form of shells with various shapes using 3D printing to control/modify the drug release of encapsulated instantaneous-release tablets. This method allows one to produce original products with changeable drug release profiles.Generally, 3D printing is a desirable tool for designing targeted and controlled drug release systems since it allows the manufacturing of unique organic structures that can be used for implants or transdermal distribution.

Revolutionizing the manufacturing of complex dosage forms:

By making it possible to create individualised and accurate dosage forms with intricate geometries and specific medication release profiles, Complex dosage form production could be revolutionised by 3-D printing.This may contribute to better patient outcomes while lowering the expenses and intricacy of the present methods of drug production[43].

One of the main advantages of 3D printing is its capacity to create exact geometries with tailored drug release profiles in production of complicated dosage forms. This feature can help to ensure that the correct dosage of medication is given to the correct body site at the correct moment. This can improve the safety and efficacy of drugs as well as lower the possibility of side effects[34].

The goal of ongoing research into 3D printing for pharmaceutical applications is to increase the scalability and commercial feasibility of this technology while also allowing the manufacturing of more intricate and exact dosage forms. As this technology advances, it could completely transform pharmaceutical manufacture and distribution, providing patients with more individualised and effective treatments.

Three- dimensional (3D) printing has changed pharmaceutical dosage formulations. 3D printing is a method for producing three-dimensional objects by stacking layers of materials[110,111]. Using this technology allows one to create complex dosage forms with forms inaccessible to conventional manufacturing processes.Apart from organ-on- chip uses, 3D printing can be applied to produce pharmaceutical solid dosage forms tailored for specific dosing schedules. Many drugs have been investigated using 3D technology in order to produce novel solid dosage forms[112]. Furthermore helping soft materials, food, pharmaceutical dosage forms, and medicinal uses 3D printing technology[113].The capacity of 3D printing to transform the manufacturing of complex dosage forms is tremendous and will only grow during the next few years.

Customized Dosage Forms Established with 3D Printing:

Customised dosage forms could be created using 3D printing technology, according one study. Using a fused deposition modeling (FDM) 3D printer, the researchers produced a range of dosage forms including capsules, tablets, and multi-compartment capsules. The dosage forms were tailored for every individual patient depending on their age, weight, medical condition, and particular medication requirements[114].

Apart from personalisation, 3D printing technology presents the possibility to improve medicine distribution by means of complex dosage forms with specific release profiles. For example, a paper published in the International Journal of

Pharmaceutics showed how 3D printing technology might create an oral dose form with a modified release profile[112].

All things considered, the evolution of 3-D printing technology might change the pharmacy sector by allowing more customized and efficient drug delivery strategies. However, there are still difficulties to be resolved, such as quality assurance, material science, and regulatory compliance.

Pharmaceutical companies frequently employ 3-D printing technology to manufacture individualised dose forms. By allowing more tailored and efficient drug delivery techniques, the evolution of 3D printing technology has the overall power to transform the pharmacy sector.However, there are still difficulties to be resolved, such as quality assurance, material science, and regulatory compliance.

Pharmaceutical companies frequently employ 3D printing technology to manufacture individualised dose forms[111]. It has been applied using powder bed inkjet printing to produce oral solid dosage forms, selective laser sintering (SLS), stereolithography (SLA), and fused deposition modelling (FDM) (PB). The first study examining the application of 3D printing for oral medicine dosage forms was released in 2017, and it looked at the characteristics of printed tablets' drug release. Since then, studies have been done to create a variety of personalised dose forms utilising 3D printing. This paper will give a summary of several 3D printing techniques, 3D-printed solid dosage forms, and 3D-printed organ-on-chip applications.[112].

3D printing in pharmacy: difficulties and constraints:

Although 3D printing offers possible benefits for personalised treatment and pharmaceutical manufacturing, several challenges and restrictions must be addressed if this technology is to be extensively applied in the pharmacy. One major challenge is the inadequate availability of materials fit for 3D printing in uses related to drug delivery. Many of the presently available 3D printing materials are not suitable for use in pharmaceuticals due to their toxicity or other negative effects on the body. This has made it essential to develop new materials capable of controlled release of drugs, biocompatibility, and security[115].

The requirement for specialised tools and knowledge to develop, produce, and test 3D printed dosage forms is another difficulty. For many pharmaceutical companies, this can be a hurdle to acceptance, and it might need expensive investments in new equipment and employee training[17].

Furthermore using 3D printing in pharmaceuticals presents legal challenges. The safety and efficacy of these products remain many unresolved questions, thus the development and manufacturing of 3D printed dosage forms might need more regulatory clearances and control[116].

The cost-effectiveness and scalability of 3-D printing for the manufacturing of drugs are both constrained. While customisation and accuracy are benefits of 3D printing, it may not always be the most efficient or economical choice for large-scale production[3].

The ability to produce treatments in a decentralised and personalised manner thanks With 3D printing, the pharmaceutical manufacturing industry could be revolutionised.[117]. Before 3D printing is extensively applied in a pharmacy, some challenges and limitations must be solved[118]. Technical difficulties like inadequate mechanical characteristics and high friability of printed products, as well as regulatory problems like a lack of guidelines on 3D-printed dosage forms, are some of these[133].In the event of an occurrence, culpability and duty must also be discussed. Despite these difficulties, 3D printing has benefits including straightforward procedures, excellent flexibility, high repeatability, and precise medication loading. Additionally, it has the potential to enhance the use of current active pharmaceutical components in therapeutic formulation and administration. Additionally, patients can immediately create customised dose forms in a drugstore or even at home[119].Overall, Although 3-D printing is an amazing technology with many possible applications in the field of pharmacy, more research is needed to solve present problems and restrictions.

Regulatory Issues of 3D Printing in Pharmacy:

Addressing the major regulatory issues raised by the use of 3D printing in pharmacies will help to guarantee patient safety and efficiency. Beyond what is required for traditional manufacturing techniques, developing and manufacturing 3D printed pharmaceuticals and devices could need more control and regulatory approvals. Guidelines published by the Food and Drug Administration (FDA) in the United States define their regulatory approach for 3D printed medical equipment and drugs. These materials underline the need of extensive testing and analysis to ensure the safety and efficiency of 3D printed objects[120].

Similar to this, the EMA had also released guidelines on how to regulate medical products made using 3D printing, such as medications and equipment. In addition to stressing the necessity of a risk-based regulatory strategy, this guideline also highlights the significance of quality control and assurance throughout the development and production process[121].

Despite these initiatives, there are still a lot of unsolved problems regarding the legal requirements for 3D printed medicines and devices, and as the technology develops, more instructions may be required.

3D printing in pharmacies is governed by the US Food and Drug Administration (FDA)[122]. Not the 3D printers themselves, but rather the medical products produced using 3D printing, the FDA controls Depending on the type of product being developed, the intended use, and any possible patient risks, a regulatory review could be requiredMedical 3D printing done outside of FDA guidelines is under very little official control.State medical boards could be able to exercise some authority should a particular healthcare facility or individual physician be found to be using 3D printing in a risky or unethical manner. Legal marketed devices created without 3D printing have to follow the same laws.The FDA states its views on the PoC 3D printing of medical devices by hospitals or individual doctors in a discussion paper titled "Discussion Paper: 3D Printing Medical Devices at the Point of Care."But the FDA still doesn't have any explicit guidelines for 3D printing in the pharmaceutical or biologic industries, Therefore, more investigation and debate are required to make sure that these items are regulated properly.

Technical Limitations of 3D Printing:

3D printing could transform the manufacturing and distribution of drugs, but several technical problems still have to be addressed before the technology is generally applied in the pharmaceutical industry. Among these restrictions are the availability of suitable materials, 3D printing technology's accuracy and precision, and the scalability of the manufacturing process[123].For instance, the resolution and layer thickness With 3D printers, one could be able to limit the accuracy of produced medications.items, particularly for small doses or highly strong medications. Furthermore, for some applications involving medication delivery, the durability and biocompatibility of printed materials may be a problem[53].

In a pharmaceutical production facility, developing and implementing specific equipment and knowledge that may be necessary for the 3-D printing medication can be expensive and time-consuming.

Therefore, more research and development are needed to overcome technical challenges and fully benefit from 3D printing even if it has great potential for drug delivery and other pharmaceutical uses.

3D printing is a disruptive technology having the ability to alter manufacturing and production[116]. Usually by layering materials like plastic, metal, or ceramic[4], this technique transforms digital models into three-dimensional objects. Among the several advantages 3D printing offers over traditional manufacturing methods are fast time to market and delivery, the ability to create complex shapes and geometries at a reasonable cost, and the integration of several components into a single product. Technical restrictions abound in the 3D printing process, though. Among these are learning about 3D design, gaining access to tools including printers, scanners, and software, and knowing little about 3D printing technology.Furthermore limited are the materials that 3D printers can print. Typical 3-D printing materials are plastics, metals, ceramics, composites, and bioplastics[124].

Cost and Accessibility issues: The price and availability of the technology are two major drawbacks of 3D printing in pharmacy. Purchase and maintenance costs for 3D printers can be high, and material costs, particularly for specialised or biocompatible materials, can be high as well[17].Additionally, a barrier to adoption may be the knowledge and training necessary to use 3D printers and create pharmaceutical items, particularly for smaller or less well-funded enterprises[106].Additionally, certain businesses may find it difficult to use 3D printing in pharmacy due to the complicated and unpredictable regulatory and intellectual property landscape[56].Although adoption of 3D printing technology is mostly hampered by its cost and accessibility, some researchers and businesses are working to create more reasonably priced and user-friendly 3D printing systems for other pharmaceutical applications and medicine distribution[3].

Overall, the expense and accessibility of 3D printing technology continue to be major obstacles to its widespread adoption in pharmacy, although on-going research and development activities may one day assist to remove some of these obstacles.Due to its numerous methodologies and readily available materials, 3D printing has grown increasingly beneficial in environmental applications[125]. It provides a novel manufacturing strategy that can cut down on the need for resources, energy use, and CO2 emissions[126]. Cost and accessibility are still problems with 3D printing, though. While industrial machines can cost up to several million dollars, desktop 3D printers can be purchased for less than $5,000[127]. Moreover, 3D printing services are not always easily accessible or reasonably cost for consumers and producers. To improve 3D printing accessibility, researchers have developed a low-cost, highly accessible fused deposition modeling 3D printer using easily available materials in their local area. Creating plastic parts with this machine can be done at a fraction of the cost of traditional 3D printers. Furthermore modified from cheap 3D printers are bioprinting systems to reduce development costs and injector clogging issues[128]. Research is being done to increase the application of this ground-breaking technology even if 3D printing still suffers with cost and accessibility.

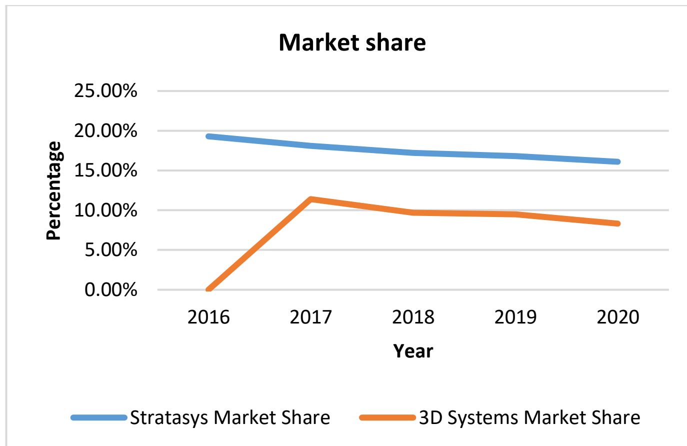
AI in 3-D printing: Artificial intelligence (AI) offers several advantages for 3D printing, including the ability to forecast the quality of the part and analyse an object before the process starts. AI can also assist in enhancing the fixing process and minimising waste in production.In order to automate 3D printing and eliminate trial-and-error usage, MIT researchers have created an AI. The AI is a machine learning system that was created with the intention of foreseeing probable mistakes in material processing during 3D printing and immediately fixing them. Additionally, it may make it simpler for engineers to add novel materials into prints, enabling them to create objects with unique chemical or electrical properties. The numerical model developed by the researchers accounts for 3D printer noise, enabling them to modify the printing process as needed.

Statistics:

Expanding at a compound annual growth rate of 21.5%, from 2019 to 2024, Marketsand Markets projects that the worldwide 3-D printing market will reach $34.8 billion by 2024. According to the research, the healthcare sector is anticipated to be one of the main forces behind the expansion of the 3D printing market, with uses in medication delivery systems, surgical equipment, and medical implants. most firms (38%) report having used 3D printing in some form, making them the largest percentage of users of the technology. With 27% of firms reporting use of the technology, Europe has the second-highest percentage of users. With only 18% of organisations reporting use of 3D printing, Asia has the lowest percentage of users.

Research by the 3D Printing Industry shows that over the past ten years, the proportion of people using 3D printing has been progressively rising.In contrast to 2020, when 71 percent of the organisations surveyed will be adopting 3D printing, only 28 percent did so in 2011. Over the past ten years, this shows a tremendous growth in the adoption of the technology.

Statista projects that 3D printing's worldwide market value in 2020 will be rather $12.6 billion. following details on the market shares of the top 3D printing firms globally during the previous five years are also provided in the report:



Grand View Research estimates that the market for 3D printed medications was worth USD 72.02 million in 2021 and is projected to rise at a CAGR of 15.32 percent from 2022 to 2030. The market is anticipated to reach USD 269.74 million and USD 86.24 million, respectively, by 2030. North America now maintains a strong position in the market for 3D printed pharmaceuticals, with a share of 37.23 percent in 2021. In many respects, including lowered costs and faster manufacturing times, 3D printing can help clinical practice and the pharmaceutical industry.Being the first profession to recognise the possibilities for medications in 3D printing, pharmacists have been the driving force behind the industry.Clinical pharmacy practise could undergo a transformation thanks to 3D printing as mass-produced drugs are replaced with individually designed ones that are both safe and effective[93]. Medical products produced with 3D printing but not 3D printers themselves are supervised by the U.S. Food and Drug Administration (FDA).Among the 3D-printed medical products now on the market approved by the FDA are drug delivery systems for pseudoephedrine and polypills with several active ingredients. By allowing the decentralised and individualised production of treatments, 3D printing has the general ability to totally revolutionise the manufacturing of pharmaceuticals.

Application of 3D printing

Drug Delivery Systems:Customized drug delivery systems that distribute medication at a particular pace or place within the body can be made using 3D printing[17].

Medical Devices: Customized medical products, including prostheses, surgical equipment, and dental implants, One can create it with 3D printing.[62].

Formulation Development: Drug formulations with complicated structures, such as multi-layer tablets with various release profiles, is made using 3D printing[129].

Tissue Engineering: 3D printing[130] allows one to create scaffolds for tissue engineering—that is, for replacement or repair of damaged tissue.Applied in many disciplines, including manufacturing, medicine, architecture, bespoke fabrication, and research, rapid prototyping technology sometimes referred to as 3D printing has[4,131]. 3D printing combined with a range of materials allows one to create complex objects. 3D printing finds application in the medical field for occupational therapy tools. In the geosciences, 3D printing has been applied to create components for research including vacuum components and magnetic shielding. Artists including Martin John Callanan have also used it at the Bartlett School of Architecture. Apart from its current applications, 3D printing could be used in the future to produce open-source scientific tools as well as real objects from digital designs [132]. As the technology develops, more original uses for 3D printing are unavoidable.

CONCLUSION

3D printing technology has the ability to totally revolutionize the pharmaceutical industry by allowing the customizing of pharmaceutical products, the manufacture of complex dose forms, and the development of innovative drug delivery systems. Bioprinting can generate living tissues and organs for use in regenerative medicine. Nonetheless, the use of 3D printing in pharmacies also faces significant challenges including technological limitations, legal difficulties, and issues of cost and accessibility. Constant research and development initiatives help to remove these challenges and realize the full possibilities of 3D printing technology in pharmacy.3D printing technology has several rather different possible applications in the pharmacy. Among the several opportunities are complicated dosage forms, bioprinting for regenerative medicine, creative drug delivery systems, tailored treatment, and more. Although 3D printing in pharmacies presents certain challenges and limitations, present research and development efforts are meant to remove these barriers and realize the complete possibilities of this technology. As the field of 3D printing develops, it is expected that it will become ever more important for the production and distribution of drugs. Future projects on research and development have to be concentrated on conquering these challenges and spotting innovative ideas to remove current obstacles. Developments in bioprinting and personalised medicine have the area of pharmacy changing; but, doing so will need ongoing investment and multidisciplinary collaboration. As the technology advances, it will be imperative to carefully balance the possible benefits against the challenges and restrictions to reach a day when 3D printing is a dependable, useful, and reasonably priced means of manufacturing and distribution of drugs.

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