WORLD JOURNAL OF PHARMACEUTICAL RESEARCH
Coden USA: WJPRAP Impact Factor 8.63
Volume 15, Issue 11, 2638-2652. Review Article ISSN 2277–7105

3D PRINTING APPLICATION IN TRANSDERMAL DRUG DELIVERY SYSTEM

Harshil Soni*, Hitesh Jain, Yagnesh Modi, D. B. Meshram

Pioneer Pharmacy College, Sayajipura, Vadodara, India.

Article Received on 05 May 2026,
Article Revised on 25 May 2026,
Article Published on 01 June 2026,

https://doi.org/10.5281/zenodo.20537292

***Corresponding Author**

Harshil Soni

Pioneer Pharmacy College,
Sayajipura, Vadodara, India.

How to cite this Article: Harshil Soni*, Hitesh Jain, Yagnesh Modi, D.B Meshram (2026). 3d Printing Application In Transdermal Drug Delivery System. World Journal of Pharmaceutical Research, 15(11), 2638-2652.
This work is licensed under Creative Commons Attribution 4.0 International license.

ABSTRACT

The application of three-dimensional printing as a manufacturing technique for advanced transdermal delivery devices is examined in existing literature. Three-dimensional printing refers to a variety of technologies that use computer-generated images to generate a physical object using machine-controlled tools. This method of additive manufacturing makes use of CAD designs to create physical objects through the layering process that is controlled numerically, thus allowing for the creation of intricate micro structures. The three-dimensional (3D) printing techniques used in the manufacturing process of MNs include SLA (Stereolithography), 2PP (two photon Polymerization), FDM (Fused Deposition Modelling), DLP (Digital light processing), and CLIP (Continuous liquid interface production). Compared to other traditional methods like micromolding, lithography, and etching, which are expensive and have multiple steps involved in their manufacturing process, 3D printing is advantageous for its design freedom, material savings, affordability, ease of making prototypes, and application for personalized medicine by customizing drug dosage per individual needs. Many types of MNs can be fabricated, such as solid, hollow, dissolving, coated, and hydrogel-forming MNs.

KEYWORDS: 3D Printing Microneedles; Patches; Inkjet printing; Transdermal drug delivery systems.

❖ INTRODUCTION

- 3D printing was invented decades ago to produce 3D models according to a digital plan. The technology can rapidly and economically develop a design cycle for the production of personalized drugs.[1]
- Transdermal drug delivery (TDD) is a technique for delivering drugs through the skin, providing an alternative to intravenous and oral routes that provide pain-free drug administration, lack first-pass effect, better compliance, self-medication, and minimum invasive administration of drugs. Moreover, it helps increase drug bioavailability and thus improve their therapeutic effectiveness.[2]
- TDD along with dosage forms such as transdermal patches and iontophoretic patches which have gained clinical acceptance and commercial success were investigated by scientists.[3-4]
- Three-dimensional printing allowed a straight forward manufacturing cycle to quickly manufacture a high-quality product.[5]
- The use of transdermal drug delivery system is an excellent method of delivering the dosage form via its application on the skin surface in a predictable and controlled manner while the adhesion of the dosage form is facilitated through the skin surface via passive diffusion.
- The most significant features of the transdermal drug delivery system: the pH of the formulation has to lie within the range of 5 to 9, the drugs having a low melting point of below 200°c can be used, the particle size needs to be less than 40 cm2, and the half-life of the drug has to be below 2 years.[6]
- There are various benefits offered by this technique compared to the traditional delivery techniques, such as the avoidance of first-pass Metabolism (maximum degradation of drugs because of hepatic first pass Metabolism), avoiding fluctuations in the dosage formulation, and releasing the drugs in a prolonged way, where it can be withdrawn from the body at any time, as well as improve patient compliance.[7]

❖ 3D Printing Technology

- Three-Dimensional (3D) printing or 3D technology is a big revolution in drug development in order to make revolutionary changes in the health care system and is currently used in the field of tissue engineering, dentistry, aerospace engineering, and construction.[8]

- Three-Dimensional printing is a 3-D process associated with Computer-Aided Design (CAD) associated with developing pharmaceutical dosage forms, flexibility, time-saving, and improving patient compliance.[9]
- The upcoming trend for 3D printing technology affects the treatment of patients in relation to patients of pharmacogenetics, polymorphism, and chronic diseases through the increase of therapeutic activity with minimum adverse effects.
- 3D printing is also associated with different types of dosage forms such as sustained-release tablets, pills, and a transdermal patch that has several dosage forms in one dose for curing several diseases.[10]
- The concept of 3D printing technology was developed by Charles Hull in 1984 and then patented in 1986.[11]
- FDM and SLS technologies were developed towards the end of the 1980s. 3D, meaning 3-dimensional printing technology, was invented by Massachusetts Institute of Technology and then patented in 1993.[12]
- In 2015, the first drug based on 3D printing technology, namely Spritam, was invented, and it was approved by FDA (Food and Drug Administration).

❖ Advantages of 3D Printing Technology

- High capacity for loading of drugs with precision and accuracy, and is capable of making the stability of powerful drugs.[13]
- Minimal loss of materials with economic efficiency.
- Peptides and proteins with low solubility and low therapeutic indices as well as poorly soluble drugs can be formulated using 3D printing technology.
- Increased patient compliance.
- Using 3D printing technology, drugs with carriers increase their absorption rate, and therefore increase their bioavailability.
- Personalized Medicine: The use of 3D printing makes it feasible to manufacture personalized drug delivery systems which are tailor-made to the needs of individual patients.[14]
- Reduction in Side Effects: As a result of the control in the delivery of drugs in a target-oriented manner, the side effects of the process can be greatly reduced.

❖ Disadvantages of 3D Printing Technology

- The price of machines is very costly, and their maintenance is very hard.

- Not appropriate for mass production.[15]
- Need of skilled manpower for operating machines.
- Raw materials for manufacturing are scarce.[16]
- Moving again and again from one place to another place is tough.
- Hazardous items that increase negative effects.
- Therapeutic window is not easily maintainable.[17]
- Post-printing processes: Some techniques require washing, curing, or post-processing operations after printing. This will add time to production and possibly variability.
- Drug instability during printing: Certain printing techniques use high temperatures which can cause degradation of temperature-sensitive APIs. SLA printing technique uses UV light and is likely to affect drug stability.

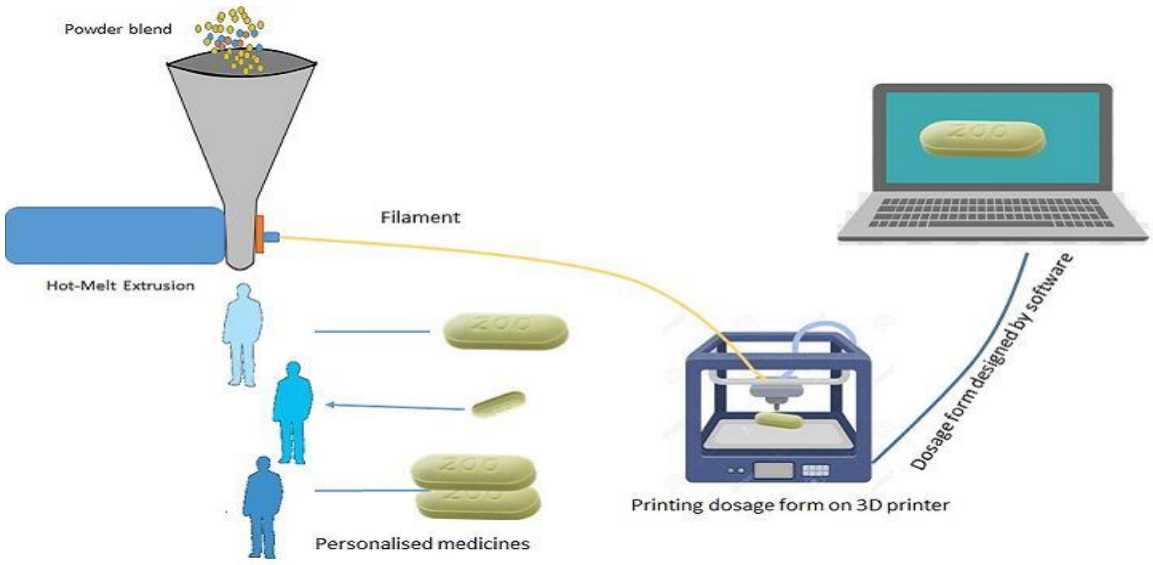

Fig.1: Schematic Diagram of 3D Printing Technology.

❖ **3D Printing technology on Transdermal Drug Delivery System**

- Transdermal drug delivery is self-discrete, self-administrated, painless application, providing dosage forms via the skin with a regulated and consistent drug release at the targeted site, and becoming excessively popular among future researchers owing to the total dose amount being delivered at once.[18]
- The technology of 3D printing is becoming a booming technology to the industries as well as investigating transdermal drug delivery systems for the improvement of effectiveness, economical cost, and rapid technology.[19]

- The technology of 3D printing uses printing processes to the transdermal patches to increase interest among children and adults.[20]
- Currently, the technology of 3D printing is concentrating on transdermal drug delivery because of its efficacy, absorption rates, and certain physicochemical properties which may vary between individuals and can be managed easily by this technology.
- There are several benefits associated with TDD compared to oral administration of drugs, which bypasses first-pass effect, ensures protection of sensitive drugs from degradation in the acidic environment of the GI system.[21]
- As for the application of 3D printing technology in transdermal drug delivery, microneedles, medicated patches, and multiplexing contact layers for skin are created using this technology.
- These microneedles are particularly valuable since they provide microchannels in the skin and facilitate the passage of small molecules, peptides, proteins, and vaccines.[22]
- The global TDD market has played a crucial role in delivery of various drugs including, for example, in such fields as pain relief, hormone, central nervous system diseases, cardiovascular diseases, and many more such as smoking cessation.[23]
- TDD market is expected to be quite large.

❖ **Types of 3D-Printed Transdermal Drug Delivery Systems**

Patches

➢ The transdermal drug therapy gained recognition on an international scale with the transition from the system without patches to the TDD patch in the 1970s, with the development of the scopolamine patch as it offered a more sustainable approach of drug delivery.

➢ The patch contains the drug in a specific formulation, releasing the drug in a steady manner.

➢ Two main approaches have been developed for the pro-duction of the drug storage patch; in the first method, called the 'reservoir patch' where a compartment that contains the drug is formed, where a membrane controls the drug release rate to the skin.

➢ Two main types can be distinguished in the design of the 'matrix patch'. In the first type, the drug is encapsulated in a polymer matrix, whereas in the second, only an adhesive layer exists containing the drug.

➢ Firstly, since the drug absorbed through the skin would be temporarily stored in the Stratum Corneum before slowly diffusing to deeper tissues, there will be a lag between

the patch being applied to the point where an effective concentration of the drug is reached.

- The microporous membranes used in the reservoir type of patch also ensure the delivery rate will be significantly less than noted with the natural skin.

Microneedles[24]

- Microneedles (MNs) are micrometer-sized needles that puncture through the stratum corneum for drug delivery, vaccination, and bioactive agent transfer.
- MNs can be composed of ceramic, polymer, and metal materials and produce micro-channels that circumvent skin barriers.
- Sonophoresis, iontophoresis, and electroporation are technologies used to increase the permeability of the skin layers for enhanced transdermal delivery.
- Sonophoresis employs ultrasonic waves to generate pores through oscillations, pressure differences, and local temperature changes.
- Iontophoresis employs low electrical voltage to transport drug ions across the skin, whereas electroporation uses pulses of high voltage to generate cavities. Etching, lithography, molding, and laser cutting have been used to manufacture conventional MNs but are typically expensive and complicated.

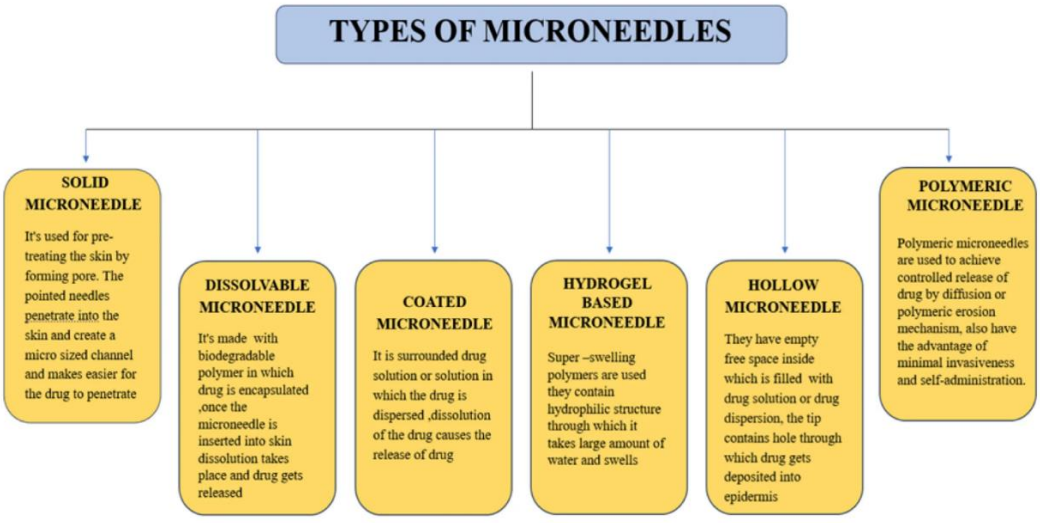

Fig.2: Types of Microneedles.

- **Solid microneedles**: These are designed to puncture the skin to form temporary microchannels where the drug formulation or the patch is placed after removal.

- **Coated microneedles:** The outer surfaces of microneedles are covered by the drug formulations, and these formulations get released into the skin immediately upon application due to dissolution.
- **Dissolving microneedles:** The microneedles in this case are made up of biodegradable or soluble polymers containing the drug formulations. Upon penetration into the skin, the microneedles dissolve into the skin and release the loaded drug formulation. It is among the most commonly researched 3D printed transdermal system.
- **Hollow microneedles:** In this case, the microneedles have an inner lumen that allows drug formulations to be delivered directly into the skin layers.
- **Hydrogel-forming microneedles:** This type of microneedles forms hydrogels when they penetrate the skin and allow sustained delivery of drugs into the skin layers.

❖ **Methods of manufacturing 3D printed Microneedles**

A. Fused deposition Modelling (FDM)

- The FDM (Fused Deposition Modeling) technique is an inexpensive 3D printing technology that is highly available.[25]
- This process requires thermoplastic filament that melts and builds up structure in layers.
- Ideal for the production of arrays of microneedles (MNs) with desired dimensions and density.
- Allows the creation of biodegradable and biocompatible MNs from polymers.[26]
- Additional treatments such as chemical etching enhance the precision of tips.
- However, FDM suffers from low resolution and low processing speeds.

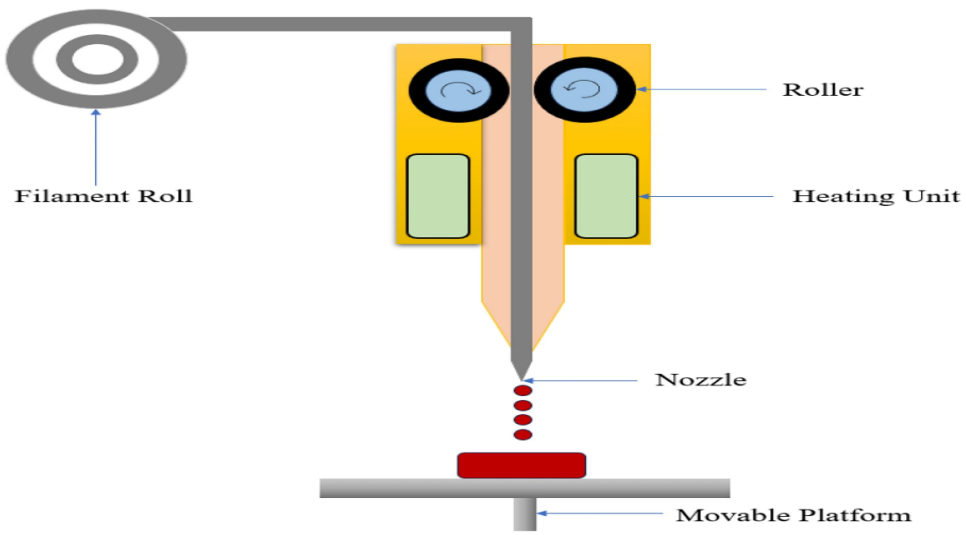

Fig.3: Schematic Diagram of Fused deposition modelling.

B. Two-photon polymerization (2PP)[27]

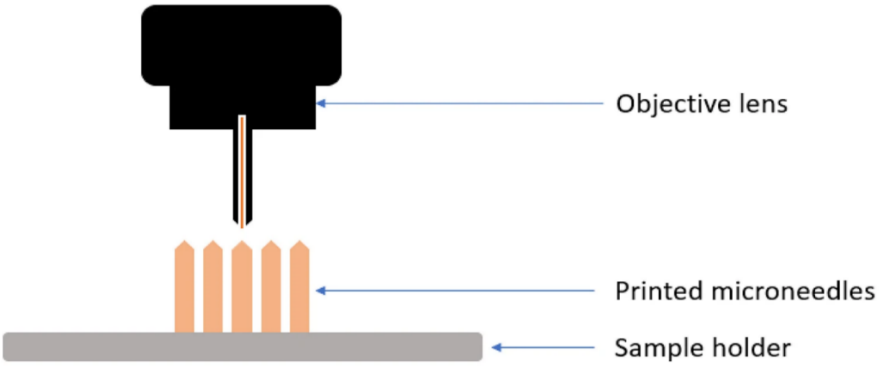

Fig.4 Schematic Diagram of Two-photon polymerization (2PP)

- 2PP (Two-Photon Polymerization) is capable of producing very intricate micro/nano-scale structures with great precision.
- Uses a femtosecond near-infrared laser to selectively polymerize the photosensitive resin through double-photon absorption.
- Takes place when the minimum threshold level of energy is achieved, leading to the formation of very accurate 3D structures (voxels).
- One of the most precise methods for 3D printing.
- Used to produce templates for MN array in different geometrical configurations including conical, pyramidal, cruciform, pedestal MN arrays.
- Fabricates reproducible and reusable molds for MN arrays used for drug delivery applications (Cabotegravir Sodium & Ibuprofen Sodium).

C. Stereo lithography appearance (SLA)[28]

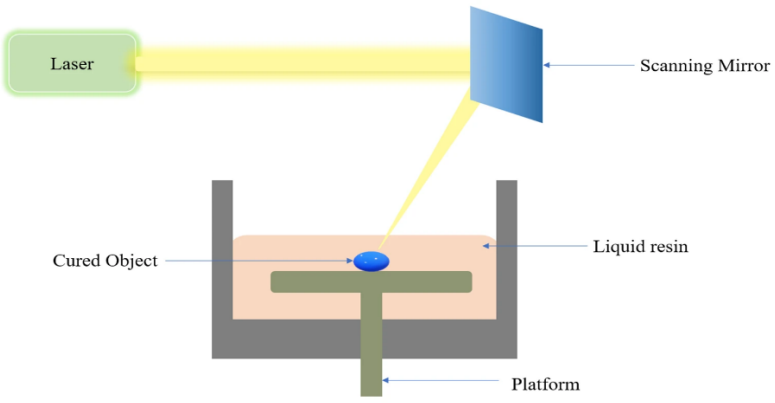

Fig.5 Schematic Diagram of Stereo lithography appearance (SLA).

- One of the most popular forms of 3D printing is stereolithography (SLA), invented by Charles Hull in 1986.
- It uses vat photopolymerization technology, where a liquid polymer material hardens when exposed to ultraviolet light.
- The process involves using a computer-operated ultraviolet laser to cure the polymer in layers, resulting in the creation of precise 3D parts.
- SLA can produce very accurate and defect-free models.
- However, the print quality relies heavily on variables such as laser strength, exposure time, scanning speed, and photo-initiator levels.
- It can be used in making MNs, whether solid or hollow.

D. Digital light processing (DLP)[29]

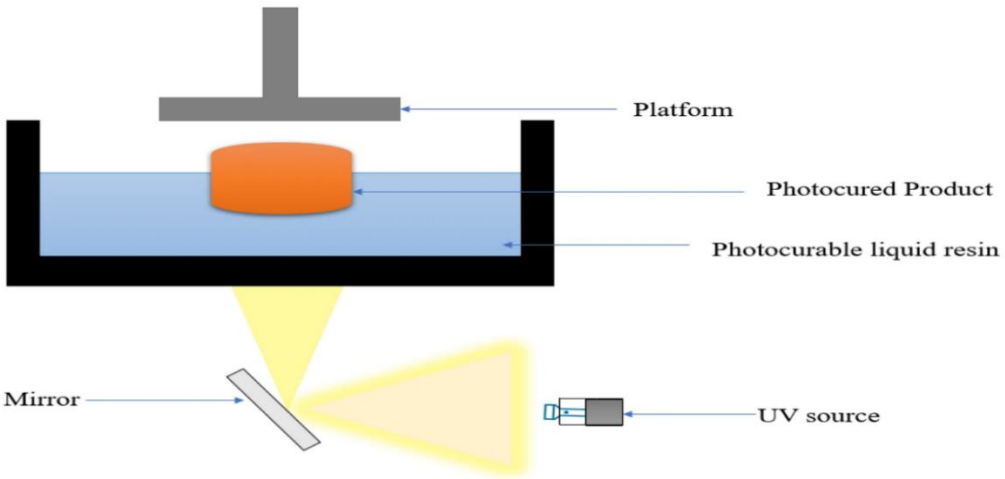

Fig.6 Schematic Diagram of Digital light processing (DLP)

- Digital Light Processing (DLP) is a form of photopolymerization just like SLA.
- In this process, digital micromirror device and UV projector are used to solidify the liquid resin.
- A 3D design needs to be sliced into layers using certain software.
- Different from SLA, this process cures the whole layer at one go via the projection of light onto the full cross-sectional area of each layer.
- The platform moves down gradually, thus layer upon layer creation of the object.

E. Continuous liquid interface production (CLIP)

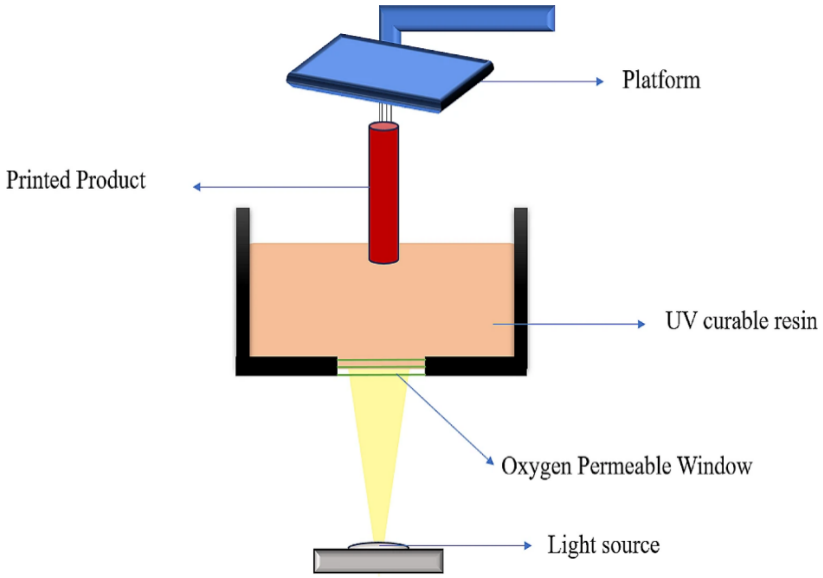

Fig.7: Schematic Diagram of Continuous liquid interface production.

- CLIP (Continuous Liquid Interface Production) is an improved and quicker 3D printing process than SLA and DLP.[30]
- Utilizes light exposure for curing of the photopolymer liquid and creating object sections.
- Utilizes next-generation projectors (LED and laser based) rather than typical digital projectors.
- Includes a resin-insolating "dead zone" layer that ensures resin will not cure entirely on the bottom.
- Allows for continuous printing, in contrast to layer-by-layer printing methods.[31]
- Ensures much quicker printing rate with smoother object creation.

❖ Present Aspects and Future Aspects

- ➢ There is tremendous potential for enhancing future drug delivery systems using 3D printing technology.[32]
- ➢ Biopolymers have been used extensively owing to their safety and efficacy. They are biocompatible, biodegradable, nontoxic, and nonimmunogenic.
- ➢ Chitosan and Gelatin increase mucoadhesion, whereas Polyvinyl alcohol and Polylactic acid are commonly employed for formulations.[33]
- ➢ New developments involve bioprinting of transdermal patches (particularly for paediatric patients) and reconstructive organs/skin.

- Emerging areas are customized transdermal treatment and responsive or smart drug delivery systems.[34]
- Challenges include incompatibility of drugs, intricate fabrication processes, and commercialization obstacles.
- Combinations such as microneedles (MNs) and nanomedicine have significant potential but remain in the preclinical or early clinical stages.[35]

❖ **Applications on 3D printing for Transdermal drug delivery system**

- It provides controlled drug delivery accurate drug positioning, and can be used to design minimally invasive delivery systems such as microneedles (MNs).[36]
- It can provide biomimicking design using natural structures for MNs such as insect sting and plant thorns to deliver drugs effectively.

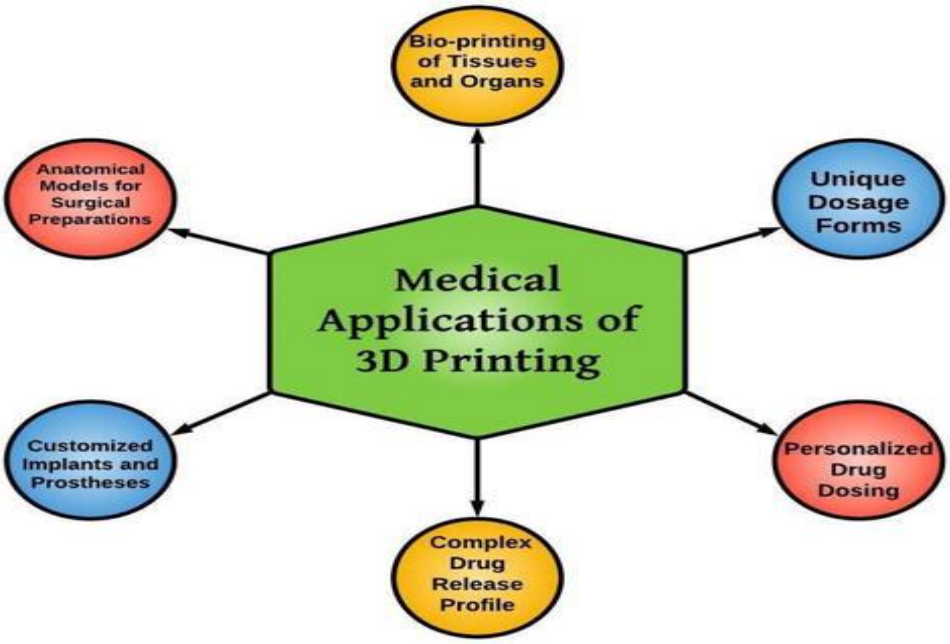

Fig.8 Diagram of Medical Applications of 3D printing.

- It provides bioprinting, wherein biological phenomena such as angiogenesis and tumor formation are mimicked for pharmaceutical and biomedical purposes.
- It ensures greater customization and manipulation as compared to the traditional methods.
- It can create individualized drug patches according to the specific needs of each patient, including his age, weight, and medical conditions.[37]
- 3D printers have become one of the most innovative and effective ways of modification and customization of pharmaceutical formulations.

- 3D-printed microneedles have been gaining more interest recently since they enable bypassing the skin barrier for the delivery of various biologics, peptides, proteins, and even vaccines.
- Drug-loaded surface coatings could be added to microneedles in order to ensure their fast dissolution upon insertion into the skin layer.
- The microneedle technology is suitable for administering vaccines
- The microneedle technology is suitable for the targeted administration of anti-cancer drugs
- The microneedle technology is suitable for administering analgesic drugs
- The microneedle technology is suitable for administering topical treatments.

❖ CONCLUSION

In conclusion, 3D printing is a novel technology, which is evolving and has the ability to bring a great revolution in the pharmaceutical and health sector in the future. It can be applied in drug delivery systems, dentistry, bioprinting, and even in transdermal drug delivery. The 3D printed drug approved by FDA in 2015 marked the real-world applicability of the technology. Researches and developments are continuously being done in this field for advancement of personalized medicine and organs' repair, among other future uses.

❖ REFERENCES

1. Norman, J.; Madurawe, R.D.; Moore, C.M.V.; Khan, M.A.; Khairuzzaman, A. "A new chapter in pharmaceutical manufacturing: 3D-printed drug products." *Adv. Drug Deliv. Rev*, 2017; 108: 39–50.
2. Ali R, Mehta P, Arshad MS, Kucuk I, Chang M-W, Ahmad Z. "Transdermal microneedles—a mater perspective." *AAPS PharmSciTech*, 2020; 21:12. 1560-3.
3. Hegde NR, Kaveri SV, Bayry J. "Recent advances in the administration of vaccines for infectious diseases: microneedles as painless delivery devices for mass vaccination." *Drug Discov Today*, 2011; 16: 1061–8.
4. Aich K, Singh T, Dang S. "Advances in microneedle-based transdermal delivery for drugs and peptides." *Drug Deliv Transl Res*, 2022; 12: 1556–68.
5. Elkasabgy NA, Mahmoud AA, Maged A. "3D printing: an appealing route for customized drug delivery systems." *Int JPharm*, 2020; 588: 119732.
6. Zhou X, Hao Y, Yuan L, Pradhan S, Shrestha K, Pradhan O. "Nanoformulations for transdermal drug delivery: a review." *Chin Chem Lett*, 2018; 29(12): 1713-24.

7. Opatha SAT, Titapiwatanakun V, Chutoprapat R. Transfersomes: "A promising nanoencapsulation technique for transdermal drug delivery." *Pharmaceutics*, 2020 9; 12(9): 855.
8. Beg S, Almalki WH, Malik A, Farhan M, Aatif M, Rahman Z. "3D printing for drug delivery and biomedical applications." *Drug Discov Today*, 2020; 25(9): 1668-81.
9. Elkasabgy NA, Mahmoud AA, Maged A. "3D printing: an appealing route for customized drug delivery systems." *Int JPharm*, 2020; 588: 119732.
10. Souto EB, Campos JC, Filho SC, Teixeira MC, Martins Gomes C, Zielinska A. "3D printing in the design of pharmaceuticals dosage forms." *Pharm Dev Technol*, 2019; 24(8): 1044-53.
11. Basit A.W, Gaisford S. "3D Printing of Pharmaceuticals Volume 31." *Springer International Publishing Cham*, Switzerland, 2018; 1–19.
12. Su A, Al'Aref SJ. "History of 3D printing and 3D printing applications in cardiovascular medicine." *Elsevier,* 2018; 1-10.
13. Goyanes A, Martinez PR, Buanz A, Basit AW, Gaisford S. "Personalized tablet 3D printing using fused deposition modeling." *Int J Pharm*, 2015; 494(1): 313-323.
14. Lee JW, Kim JY, Cho H, Park JH. "3D printing of transdermal patches for sustained release." *J Control Release*, 2018; 273: 134-141.
15. Vithani K, Goyanes A, Jannin V, Basit AW, Gaisford S, Boyd BJ. "An overview of 3D printing technologies for soft materials and potential opportunities for lipid-based drug delivery systems." *Pharm Res*, 2018; 7: 36-40.
16. Cordeiro AS, Tekko IA, Jomaa MH, Vora L, McAlister E, Volpe Zanutto F. "Two-photon polymerisation 3D printing of microneedle array templates with versatile designs: application in the development of polymeric drug delivery systems." *Pharm Res*, 2020 Aug 27; 37(9): 174.
17. Mohanasundaram S, Rangarajan N, Sampath V, Porkodi K, Prakash MVD, Monicka N. "GC-MS identification of anti-inflammatory and anticancer metabolites in edible milky White mushroom (Calocybe indica) against human breast cancer (MCF-7) cells." *Res J Pharm Technol*, 2021; 14(8): 4300-6.
18. Svenskaya YI, Genina EA, Parakhonskiy BV, Lengert EV, Talnikova EE, Terentyuk GS. "A simple non-invasive approach toward efficient transdermal drug delivery based on biodegradable particulate system." *ACS Appl Mater Interfaces*, 2019 15; 11(19): 17270-82.

19. Alam MS, Akhtar A, Ahsan I, Shafiq-Un-Nabi S. “Pharmaceutical Product Development exploiting 3D printing technology: conventional to novel drug delivery system.” *Curr Pharm Des*, 2018; 24(42): 5029-38.
20. Mohanasundaram S, Rangarajan N, Sampath V, Porkodi K, Pennarasi M. “GC-MS and HPLC analysis of antiglycogenolytic and glycogenic compounds in kaempferol 3–O–gentiobioside containing Senna alata L leaves in experimental rats.” *Transl Metab Syndr Res*, 2021; 4: 10-7.
21. Economidou SN, Douroumis D. “3D printing as a transformative tool for microneedle systems: recent advances, manufacturing considerations and market potential.” *Adv Drug Deliv Rev*, 2021; 173: 60-9.
22. Krieger KJ, Bertollo N, Dangol M, Sheridan JT, Lowery MM, O’Cearbhaill ED. “Simple and customizable method for fabrication of high-aspect-ratio microneedle molds using low-cost 3D printing.” *Microsyst Nanoeng*, 2019; 9: 5-42.
23. Wicker RJ, Kumar G, Khan E, Bhatnagar A. “Emergent green technologies for cost-effective valorization of microalgal biomass to renewable fuel products under a biorefinery scheme.” *Chem Eng J*, 2021; Pg no.415.
24. Ashlesh Prabhu, Vishal Baliga, Raghavendra Shenoy, Akanksha D. Desai, Usha Y. Nayak. “3D printed microneedles: revamping transdermal drug delivery systems.” *Drug Delivery and Translational Research*, 2025; 15: 436–454.
25. Joo Y, Shin I, Ham G, Abuzar SM, Hyun S-M, Hwang S-J. “The advent of a novel manufacturing technology in pharmaceutics: superiority of fused deposition modeling 3D printer.” *J Pharm Investig*, 2020; 50: 131–45.
26. Goole J, Amighi K. “3D printing in pharmaceutics: a new tool for designing customized drug delivery systems.” *Int J Pharm*, 2016; 499: 376.
27. Cordeiro AS, Tekko IA, Jomaa MH, Vora L, McAlister E, Volpe-Zanutto F, et al. “Two-photon polymerisation 3D Printing of Microneedle array templates with versatile designs: application in the development of Polymeric Drug Delivery systems.” *Pharm Res*, 2020; 37: 174.
28. C. W. Hull, "Apparatus for production of three-dimensional objects by stereolithography," *U.S. Patent*, 1986; *4:* Pg.no-575.
29. Kadry H, Wadnap S, Xu C, Ahsan F. “Digital light processing (DLP) 3D-printing technology and photoreactive polymers in fabrication of modified-release tablets.” *Eur J Pharm Sci*, 2019; 135: 60–7.

30. Quan H, Zhang T, Xu H, Luo S, Nie J, Zhu X. "Photo-curing 3D printing technique and its challenges." *Bioact Mater*, 2020; 5: 110–5.
31. Hahn V, Kiefer P, Frenzel T, Qu J, Blasco E, Barner-Kowollik C, et al. "Rapid Assembly of small materials building blocks (Voxels) into large functional 3D metamaterials." *Adv Funct Mater*, 2020; Pg no-30.
32. Kawano M, Wang XY, Ren Q. editors. "New cost-effective via-last approach by One-step TSV after wafer stacking for 3D memory applications 69th Electronic Components and Technology Conference (ECTC)." *IEEE Publications*, 2019.
33. Jain A, Bansal KK, Tiwari A, Rosling A, Rosenholm JM. "Role of polymers in 3D printing technology for drug delivery–an overview." *Curr Pharm Des*, 2018; 24(42): 4979-90.
34. Elahpour N, Pahlevanzadeh F, Kharaziha M, Bakhsheshi-Rad HR, Ramakrishna S, Berto F. "3D printed microneedles for transdermal drug delivery: A brief review of two decades." *Int J Pharm*, 2021; Pg no-597.
35. Economidou SN, Lamprou DA, Douroumis D. "3D printing applications for transdermal drug delivery." *Int J Pharm*, 2018; Pg no:415-24.
36. Umeyor CE, Shelke V, Pol A, Kolekar P, Jadhav S, Tiwari N, et al. "Biomimetic microneedles: exploring the recent advances on a microfabricated system for precision delivery of drugs, peptides, and proteins." *Future J Pharm Sci*, 2023; 9: 103.
37. Lei IM, Jiang C, Lei CL, de Rijk SR, Tam YC, Swords C, et al. "3D printed biomimetic cochleae and machine learning co-modelling provides clinical informatics for cochlear implant patients." *Nat Commun*, 2021; Pg no-12.