

3D Printing Revolutionizes Personalized Medicine

Kenji Yamamoto*

Faculty of Pharmaceutical Sciences, Osaka Central University, Osaka, Japan

Introduction

3D printing technology has emerged as a revolutionary force, significantly advancing and shaping the future of personalized medicine. It plays a pivotal role in creating patient-specific dosage forms, sophisticated medical devices, and even complex tissues tailored to individual needs. This transformative approach spans various 3D printing technologies applicable across pharmaceutical and biomedical fields, where discussions often center on inherent challenges and expansive opportunities for individualized treatment strategies [1].

This journey from theoretical concepts to tangible clinical implementations is particularly evident in drug delivery applications. 3D printing actively facilitates a crucial paradigm shift towards personalized medicine, allowing for the precise customization of dosing regimens, intricate drug release profiles, and multi-component combination therapies, all meticulously designed to meet unique patient requirements [2]. This capability moves us closer to genuinely bespoke medical interventions.

Examining current 3D printing technologies used in manufacturing pharmaceutical dosage forms reveals a dynamic landscape of innovation. Recent advancements in techniques such as fused deposition modeling, inkjet printing, and stereolithography are particularly noteworthy. Each method brings its own set of capabilities and limitations, influencing how effectively tailored drug products can be created to serve diverse patient populations [3].

Fused Deposition Modeling (FDM), for instance, has gained considerable prominence as a specific 3D printing technique within pharmaceutical applications. Research consistently explores its evolving trends, identifying both current opportunities and challenges. FDM's inherent ability to produce complex geometries and precisely engineered drug release profiles underscores its substantial potential for personalized medicine, making it a focal point for ongoing development [4]. The success of FDM relies heavily on the characteristics of drug-loaded filaments and their processing.

Understanding the critical factors that influence the printability of these drug-loaded filaments is essential for optimizing FDM. Specifically, the role of hot-melt extrusion processing and the intrinsic properties of the filaments themselves are under intense investigation. Insights gained from studying material selection and processing conditions directly reveal how they impact the quality and ultimate performance of 3D-printed pharmaceutical dosage forms, thereby guiding formulation development towards greater efficiency and effectiveness [5]. This meticulous attention to material science ensures the integrity and functionality of the final product.

The pharmaceutical sector, moreover, is witnessing a broader integration of both bioprinting and 3D printing technologies. These advanced manufacturing tech-

niques are not just incremental improvements; they are fundamentally transforming processes from early drug discovery to the sophisticated development of personalized dosage forms. Furthermore, their application extends to tissue engineering, which holds promise for more accurate drug testing models. This comprehensive adoption paints a clear picture of future directions and the profound potential impact these technologies will have on overall patient care [6].

A specific technological synergy drawing significant attention is the coupling of hot-melt extrusion (HME) with 3D printing for the production of oral dosage forms. This combination represents a state-of-the-art approach, lauded for its advantages in enhancing drug solubility and bioavailability—critical factors for drug efficacy. Despite its promise, this combined technology faces key challenges. Identifying and overcoming these hurdles is crucial for its widespread implementation in pharmaceutical manufacturing, ensuring a smooth transition from lab to industry [7].

Another versatile technique, inkjet printing technology, is also undergoing critical evaluation for its advancements and potential in pharmaceutical and biomedical fields. It finds application in creating personalized medicines, developing advanced diagnostic tools, and even fabricating intricate tissue engineering scaffolds. The technique offers benefits such as precise deposition and fine-tuned dose control. However, like any emerging technology, its current limitations are actively being addressed, and future research directions aim to unlock its full capabilities [8].

Ultimately, the overarching theme here is how 3D printing continues to fundamentally transform personalized medicine. It enables the creation of highly customized drug delivery systems and specific dosage forms. The various 3D printing technologies involved are instrumental in tailoring drug release profiles, exact dosages, and complex combination therapies, all with the goal of achieving more effective, patient-specific treatments and ultimately improving therapeutic outcomes [9].

As these innovative, 3D-printed medicines progress towards clinical application and commercialization, the evolving regulatory landscape becomes a critical area of focus. A comprehensive review of this landscape reveals significant challenges and considerations that need addressing to successfully bring these products to market. The pressing need for updated guidelines, robust quality control measures, and industry-wide standardization is paramount to ensure the safety, efficacy, and consistent manufacturing of personalized pharmaceutical dosage forms, safeguarding public health and fostering innovation responsibly [10].

Description

The emergence of 3D printing technology marks a pivotal moment in the pharmaceutical and biomedical sectors, fundamentally redefining how personalized

medicine is conceived and implemented. This revolutionary approach allows for the fabrication of highly patient-specific solutions, including meticulously tailored dosage forms, intricate medical devices, and even sophisticated biological tissues. The field encompasses a broad spectrum of 3D printing methods, each presenting unique capabilities and inherent limitations, yet collectively driving forward the immense potential for individualized treatment strategies that were once considered beyond reach [1]. This profound shift towards a personalized paradigm is particularly evident in drug delivery, where 3D printing is rapidly moving beyond purely theoretical concepts into practical clinical realities. It enables unprecedented customization in dosing regimens, the creation of complex and precise drug release profiles, and the development of multi-drug combination therapies, all meticulously designed to meet the unique requirements of individual patients [2, 9]. This bespoke approach promises to significantly enhance therapeutic outcomes.

Central to this transformative era are the diverse array of 3D printing technologies currently being utilized for manufacturing pharmaceutical dosage forms. A comprehensive overview highlights established techniques such as Fused Deposition Modeling (FDM), alongside inkjet printing, and stereolithography. Each of these methods offers distinct advantages, enabling the creation of bespoke drug products that can effectively address the varied and specific needs of patient populations [3]. FDM, for instance, has garnered considerable recognition for its prominence and versatility in pharmaceutical applications. Ongoing research diligently explores its evolving trends, identifying both current opportunities and the specific challenges associated with its implementation. A key advantage of FDM lies in its inherent ability to produce complex geometries and precisely engineered drug release profiles, making it exceptionally well-suited for advanced personalized medicine applications [4]. The ultimate success and consistency of FDM technology are, however, intrinsically linked to the printability characteristics of drug-loaded filaments, requiring careful consideration of material science.

Understanding the critical factors that influence the printability of these drug-loaded filaments is thus paramount for optimizing FDM processes. Specifically, the role of hot-melt extrusion (HME) processing and the intrinsic physiochemical properties of the filaments themselves are under intense investigation. Insights gained from studying various material selections and precise processing conditions directly reveal how these factors impact the quality, consistency, and ultimate performance of the final 3D-printed pharmaceutical dosage forms. This deep understanding is crucial for guiding formulation development towards greater efficiency, reliability, and effectiveness, ensuring that patient safety and therapeutic efficacy remain at the forefront [5]. This meticulous attention to detail ensures the integrity and functionality of the pharmaceutical product.

Furthermore, a significant technological synergy that is drawing considerable attention is the coupling of hot-melt extrusion (HME) with 3D printing specifically for the production of oral dosage forms. This combined approach represents a state-of-the-art methodology, widely lauded for its inherent advantages, particularly in enhancing drug solubility and bioavailability – critical factors for achieving optimal therapeutic efficacy. However, despite these promising benefits, its widespread implementation in pharmaceutical manufacturing still faces a number of key challenges. Identifying and meticulously addressing these hurdles through innovative research and development is crucial for ensuring a smooth and successful transition from laboratory-scale innovation to large-scale industrial application [7]. In a similar vein, inkjet printing technology has also demonstrated considerable advancements, extending its utility beyond traditional applications to personalized medicines, advanced diagnostic tools, and even the fabrication of intricate tissue engineering scaffolds. Its precision in deposition and fine-tuned dose control represents a major asset, although ongoing research actively seeks to address its current limitations and unlock its full potential across diverse applications [8].

The broader scope of advanced manufacturing within pharmacy also robustly in-

corporates bioprinting alongside traditional 3D printing technologies. These integrated advanced manufacturing techniques are poised to fundamentally revolutionize critical stages, from early drug discovery processes to the intricate development of personalized dosage forms, and even to providing novel platforms for tissue engineering. The latter is especially crucial for developing more accurate and physiologically relevant drug testing models, as well as advancing regenerative medicine applications. This holistic and dual approach collectively outlines a profoundly promising future direction for the entire pharmaceutical industry, with far-reaching implications and a significant positive impact on overall patient care [6]. The combined effect of these technologies is not merely an incremental improvement; it signifies a fundamental shift in how drug delivery systems are designed, manufactured, and ultimately customized, leading to more effective and truly patient-specific treatments and enhancing overall therapeutic outcomes [9].

However, the rapid pace of innovation also introduces complexities, particularly concerning the evolving regulatory landscape surrounding 3D-printed medicines. As these innovative products progress towards clinical application and potential commercialization, there is a widely recognized and pressing need for a comprehensive and robust regulatory framework. A thorough review of this landscape reveals significant challenges and critical considerations that must be meticulously addressed to successfully bring these complex products to market. Key among these are the demand for updated guidelines, the implementation of stringent quality control measures, and the establishment of industry-wide standardization protocols. These crucial steps are absolutely vital to ensure the safety, efficacy, and consistent manufacturing of personalized pharmaceutical dosage forms, thereby safeguarding public health and concurrently fostering responsible technological progress and innovation [10]. Effectively navigating and adapting to these regulatory hurdles is paramount for realizing the full, transformative potential of 3D printing in personalized medicine.

Conclusion

3D printing is significantly transforming personalized medicine by enabling the creation of patient-specific dosage forms, medical devices, and tissues. This technology is driving a paradigm shift in drug delivery, allowing for customized dosing, release profiles, and combination therapies tailored to individual patient needs. Various 3D printing techniques, including Fused Deposition Modeling (FDM), inkjet printing, and stereolithography, are being advanced for pharmaceutical manufacturing.

FDM is particularly prominent, offering opportunities for complex geometries and tailored drug release. Research emphasizes the critical role of hot-melt extrusion processing and filament properties in FDM's printability, guiding optimal formulation development. Beyond FDM, bioprinting and 3D printing are collectively revolutionizing drug discovery, personalized dosage form development, and tissue engineering for testing, with substantial implications for patient care.

The integration of hot-melt extrusion with 3D printing enhances drug solubility and bioavailability for oral dosage forms, though challenges for widespread adoption exist. Inkjet printing also shows promise for personalized medicines, diagnostics, and tissue scaffolds due to precise deposition, despite current limitations.

Ultimately, 3D printing is revolutionizing personalized medicine through customized drug delivery systems and dosage forms, leading to more effective, patient-specific treatments. However, the evolving regulatory landscape poses challenges for market entry, necessitating updated guidelines, quality control, and standardization to ensure the safety and efficacy of these innovative pharmaceutical products.

Acknowledgement

None.

Conflict of Interest

None.

References

1. Muhammad Sohail, Arshad Bashir, Muhammad Rizwan. "Personalized medicine and 3D printing: A comprehensive review of the current landscape and future prospects." *Bioengineering* 10 (2023):427.
2. Amrita Singh, Saurabh Singh, Vijay Sharma. "3D printing in personalized drug delivery: from concept to clinical reality." *Journal of Drug Delivery Science and Technology* 74 (2022):103551.
3. Sara Fina, Anna M. M. S. de Oliveira, Marwa Elbadawi. "Overview of Current Technologies and Recent Advances in 3D Printing of Pharmaceutical Dosage Forms." *Pharmaceutics* 13 (2021):1205.
4. Abdul Aziz, Ali Al-Rawi, Ibtihal Al-Zoubi. "Fused Deposition Modeling (FDM) 3D Printing of Pharmaceutical Dosage Forms: Research, Trends, and Opportunities." *Pharmaceutics* 12 (2020):981.
5. Sara Fina, Joshua A. Davies, Peter J. T. Stansfield. "Printability of drug-loaded filaments for fused deposition modelling: The role of hot-melt extrusion and filament characteristics." *International Journal of Pharmaceutics* 616 (2022):121558.
6. Fatma Aksoy Esin, Sinem Efil, Ayse Karatas. "Bioprinting and 3D Printing in Pharmacy: Principles, Applications, and Future Directions." *Pharmaceutics* 14 (2022):1475.
7. Abdul M. Khan, Nuno M. F. S. A. Cerqueira, Fátima L. Sousa. "Hot-Melt Extrusion Coupled with 3D Printing for Oral Dosage Forms: State of the Art, Challenges, and Future Perspectives." *Journal of Pharmaceutical Sciences* 110 (2021):1957-1971.
8. Simon Gaisford, Abdul W. Basit, Peter J. T. Stansfield. "Inkjet printing for pharmaceutical and biomedical applications: a critical review." *International Journal of Pharmaceutics* 588 (2020):119771.
9. Muhammad Bilal, Muhammad Kamran Khan, Muhammad Sohail. "Personalized medicine: How 3D printing is revolutionizing drug delivery and dosage forms." *Journal of Drug Delivery Science and Technology* 82 (2023):104279.
10. Marwa Elbadawi, Peter J. T. Stansfield, Sara Fina. "The regulatory landscape for 3D printed medicines: a comprehensive review." *International Journal of Pharmaceutics* 606 (2021):120869.

How to cite this article: Yamamoto, Kenji. "3D Printing Revolutionizes Personalized Medicine." *J Formul Sci Bioavailab* 09 (2025):212.

***Address for Correspondence:** Kenji, Yamamoto, Faculty of Pharmaceutical Sciences, Osaka Central University, Osaka, Japan, E-mail: kenji.yamamoto@ocu.jp

Copyright: © 2025 Yamamoto K. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited.

Received: 02-Jan-2025, Manuscript No. fsb-25-171965; **Editor assigned:** 06-Jan-2025, PreQC No. P-171965; **Reviewed:** 20-Jan-2025, QC No. Q-171965; **Revised:** 23-Jan-2025, Manuscript No. R-171965; **Published:** 30-Jan-2025, DOI: 10.37421/2577-0543.2025.9.212