Global Journal of Research in
Biology and Pharmacy
Journal homepage: https://gsjournals.com/gjrbp/
ISSN: 2980-4221 (Online)

(REVIEW ARTICLE)

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ORGANOIDS, ORGAN-ON-A-CHIP, AND 3D BIOPRINTING IN PRECLINICAL DRUG DEVELOPMENT AND DISEASE MODELING

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Global Journal of Research in Biology and Pharmacy, 2026, 05(02), 001–003

Publication history: Received on 06 March 2026; revised on 21 April 2026; accepted on 25 April 2026

Article DOI: https://doi.org/10.58175/gjrbp.2026.5.2.0049

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ABSTRACT

Traditional preclinical models, including two-dimensional cell cultures and animal models, often fail to predict human drug efficacy and toxicity, contributing to high attrition rates in pharmaceutical development. Advanced in vitro models—organoids, organ-on-a-chip systems, and 3D bioprinted tissues—aim to better recapitulate human physiology and disease. Organoids are self-organizing three-dimensional structures derived from stem cells that mimic organ architecture and function. Organ-on-a-chip devices integrate living cells with microfluidic systems to replicate dynamic mechanical and biochemical environments. Three-dimensional bioprinting enables precise spatial deposition of cells and biomaterials to construct tissue-like structures. This review critically examines the current state and applications of these technologies in preclinical drug development and disease modeling, focusing on literature through early 2026. Organoids have been used to model genetic diseases, infectious diseases, and cancers, and to screen drug responses. Organ-on-a-chip systems have demonstrated utility in toxicology and pharmacokinetic studies, with multi-organ platforms emerging. 3D bioprinting offers scalability and architectural control, enabling fabrication of vascularized tissues. Challenges include standardization, reproducibility, scalability, and validation against human physiology. Future directions include integration of immune components, multi-organ connectivity, and regulatory acceptance as alternative methods. These platforms hold promise for reducing animal use and improving drug development efficiency.

Keywords: Organoids; Organ-On-A-Chip; 3D Bioprinting; Preclinical Drug Development; Disease Modeling; Microphysiological Systems

1 INTRODUCTION

Drug development is hindered by poor translation from preclinical models to humans. Animal models, while valuable, differ in metabolism, genetics, and disease mechanisms. Two-dimensional cell cultures lack tissue architecture and cell–cell interactions. Advanced three-dimensional models offer more human-relevant systems. Organoids, derived from pluripotent or adult stem cells, self-organize into mini-organs with multiple cell types and functions. Organ-on-a-chip devices provide dynamic culture conditions, including flow, mechanical stretch, and oxygen gradients. Three-dimensional bioprinting enables construction of complex tissues with defined spatial organization.

These technologies are increasingly used in academic and industry settings for disease modeling, drug screening, and toxicology. This review summarizes progress, applications, and challenges through early 2026.

2 ORGANOIDS

Organoids can be generated from induced pluripotent stem cells or adult stem cells for many organs, including brain, intestine, liver, kidney, and lung. They recapitulate key aspects of organ development and disease. For example, intestinal organoids have been used to study cystic fibrosis and infectious diseases like SARS-CoV-2. Tumor organoids, or patient-derived organoids, preserve tumor heterogeneity and can predict chemotherapy responses. In drug development, organoid biobanks enable high-throughput screening of efficacy and toxicity. Limitations include lack of vasculature, immune cells, and mechanical stimuli, as well as variability between batches.

3 ORGAN-ON-A-CHIP

Organ-on-a-chip systems integrate microfluidics with living cells to model tissue-level functions. Examples include lung-on-a-chip with air–liquid interface and cyclic stretch, liver-on-a-chip with perfusion, and kidney-on-a-chip with filtration. Multi-organ chips link multiple tissue compartments to study pharmacokinetics and systemic toxicity. These systems have shown promise in predicting drug-induced liver injury, nephrotoxicity, and pulmonary effects. Companies and regulatory agencies are exploring their use as alternatives to animal testing. Challenges include fabrication complexity, standardization, and validation.

4 3D BIOPRINTING

3D bioprinting deposits bioinks containing cells, hydrogels, and growth factors to create three-dimensional structures with controlled architecture. Techniques include extrusion, inkjet, and light-based printing. Bioprinted tissues can include vascular channels, improving nutrient and oxygen delivery. Applications include skin, cartilage, bone, liver, and tumor models. Bioprinted tumor models with stromal and immune cells enable study of tumor microenvironment and drug responses. Scalability and reproducibility are improving, but challenges remain in achieving high cell viability, tissue maturation, and functional integration.

5 INTEGRATION AND MULTI-ORGAN SYSTEMS

Combining organoids with microfluidic chips or bioprinting can create more complex models. For example, organoid-on-a-chip systems provide dynamic flow and mechanical cues. Multi-organ platforms connect liver, heart, kidney, and other tissues to assess drug metabolism and toxicity. These integrated systems aim to replicate human physiological responses and reduce animal testing. However, they require careful design to maintain physiological scaling and cross-talk.

6 CHALLENGES AND LIMITATIONS

Standardization of protocols, cell sources, and quality control is a major issue. Reproducibility across laboratories and batches is limited. Scaling up for high-throughput screening remains difficult, especially for organ-on-a-chip and bioprinted tissues. Cost and specialized equipment restrict widespread adoption. Validation against human data is essential; many studies are descriptive rather than predictive. Regulatory acceptance is still evolving, with agencies encouraging qualification of alternative methods.

7 FUTURE PERSPECTIVES

Future directions include incorporating immune components, vasculature, and innervation into models. Personalized medicine applications using patient-derived organoids for drug selection are promising. Artificial intelligence may aid in analysis and prediction. Multi-organ human-on-a-chip systems could replace some animal studies. Regulatory frameworks will need to adapt to accept these models as evidence in drug development. International consortia are working on standards and qualification pathways.

8 CONCLUSION

Organoids, organ-on-a-chip, and 3D bioprinting represent major advances in preclinical modeling, offering more human-relevant systems than traditional approaches. They have demonstrated utility in disease modeling and drug screening, but challenges in standardization, scalability, and validation remain. Continued development and regulatory collaboration are essential to realize their potential in reducing attrition and improving drug safety.

REFERENCES

[1] Clevers H. Modeling development and disease with organoids. Cell. 2016;165(7):1586–1597.

[2] Sato T, Vries RG, Snippert HJ, et al. Single Lgr5 stem cells build crypt-villus structures in vitro without a mesenchymal niche. Nature. 2009;459(7244):262–265.

[3] Lancaster MA, Renner M, Martin CA, et al. Cerebral organoids model human brain development and microcephaly. Nature. 2013;501(7467):373–379.

[4] Huh D, Matthews BD, Mammoto A, et al. Reconstituting organ-level lung functions on a chip. Science. 2010;328(5986):1662–1668.

[5] Bhatia SN, Ingber DE. Microfluidic organs-on-chips. Nat Biotechnol. 2014;32(8):760–772.

[6] Murphy SV, Atala A. 3D bioprinting of tissues and organs. Nat Biotechnol. 2014;32(8):773–785.

[7] Sachs N, de Ligt J, Kopper O, et al. A living biobank of breast cancer organoids captures disease heterogeneity. Cell. 2018;172(1–2):373–386.e10.

[8] van de Wetering M, Francies HE, Francis JM, et al. Prospective derivation of a living organoid biobank of colorectal cancer patients. Cell. 2015;161(4):933–945.

[9] Esch EW, Bahinski A, Huh D. Organs-on-chips at the frontiers of drug discovery. Nat Rev Drug Discov. 2015;14(4):248–260.

[10] Ronaldson-Bouchard K, Vunjak-Novakovic G. Organs-on-a-chip: a fast track for engineered human tissues in drug development. Cell Stem Cell. 2018;22(3):310–324.

[11] Zhang B, Korolj A, Lai BFL, et al. Advances in organ-on-a-chip engineering. Nat Rev Mater. 2018;3(8):257–278.

[12] Mandrycky C, Wang Z, Kim K, et al. 3D bioprinting for engineering complex tissues. Biotechnol Adv. 2016;34(4):422–434.

[13] Ma L, Barker J, Zhou C, et al. Towards personalized medicine with 3D organoids and organ-on-chip. Front Bioeng Biotechnol. 2022;10:895091.

[14] Low LA, Mummery C, Berridge BR, et al. Organs-on-chips: into the next decade. Nat Rev Drug Discov. 2021;20(5):345–361.

[15] Takebe T, Sekine K, Enomura M, et al. Vascularized and functional human liver from an iPSC-derived organ bud transplant. Nature. 2013;499(7459):481–484.

[16] Skardal A, Shupe T, Atala A. Organoid-on-a-chip and body-on-a-chip systems for drug screening and disease modeling. Drug Discov Today. 2016;21(9):1399–1411.

[17] Kankala RK, Zhu K, Sun XN, et al. Cardiac tissue engineering on the nanoscale. ACS Biomater Sci Eng. 2018;4(3):800–818.

[18] Schutgens F, Clevers H. Human organoids: tools for understanding biology and treating diseases. Annu Rev Pathol. 2020;15:211–234.

[19] Kim J, Koo BK, Knoblich JA. Human organoids: model systems for human biology and medicine. Nat Rev Mol Cell Biol. 2020;21(10):571–584.

[20] Mastrangeli M, Millet S, ORCHID partners, et al. Organ-on-chip in development: towards a roadmap for organs-on-chip. ALTEX. 2019;36(4):650–668.