The Research of Medical Science Review
ISSN: 3007-1208 & 3007-1216 Volume 3, Issue 7, 2025

NAVIGATING THE FRONTIER: EMERGING TECHNOLOGIES AND METHODOLOGIES REVOLUTIONIZING PHARMACEUTICAL SCIENCES

Mehwish Nisar[*1], Irum Afzal[2], Iqra Haider[3], Sidra Siddiqui[4], Hadia Naz[5], Zufi Shad[6]

[*1,2,3,4,5,6]*Faculty of Pharmacy, Hamdard University, Karachi*

DOI: https://doi.org/10.5281/zenodo.16400517

Keywords
CRISPR/Cas9, Gene Therapy, Cell Therapy, Artificial Intelligence, Machine Learning, Pharmacogenomics, Digital Health, Telepharmacy, Green Analytical Chemistry, Continuous Manufacturing, Blockchain, Pharmaceutical Supply Chain, Drug Development, and Drug Discovery

Article History
Received: 24 April, 2025
Accepted: 08 July, 2025
Published: 24 July, 2025

Corresponding Author: *
Mehwish Nisar

Abstract
Technological advances and new research methodologies have transformed the pharmaceutical sector. Machine learning and artificial intelligence are speeding up everything from hyper automation in drug discovery to clinical trials. Also, new digital health technologies along with gene and cell therapies are improving patient-centered care, adherence to medication, and even patient participatory medicine. In addition to these factors, blockchain technology is anticipated to improve the pharmaceutical supply chain and change the attitude towards environmentally sustainable practices.

INTRODUCTION

Technological improvements like gene editing and artificial intelligence (AI) have profoundly changed the pharmaceutical sciences.(1) Medication delivery, precision medicine, and drug discovery are changing because AI and gene editing through CRISPR are making therapeutics more personalized, efficient, and precision based.(2) These advancements do create new ethical, legal, and technical challenges.(3)

Artificial Intelligence (AI) and Machine Learning (ML) in Drug Discovery and Development

The processes of drug discovery and development are being uniquely changed by the use of technologies such as AI and ML– new approaches to optimizing, automating, and tailoring these processes.(4) From initial target selection to clinical trials, they undergo almost every step of drug development; these technologies promise a faster, more precise, and cheaper approach to drug development.(5)

Using AI and Machine Learning to Improve Drug Development and Discovery

AI/ML technologies optimize drug discovery through the analysis of large biological datasets for target identification and validation.(5, 6) It is now possible to estimate binding affinities, enhance chemical structure complexity, and screen millions of chemicals virtually.[7, 8] AI also assists in personalized therapy and ADMET predictions in clinical trial phases.[9-11]

Benefits of the Area Restrictions and Difficulties Early Finding Quicker and more precise selection of leads and targets transparency of algorithms and data quality.[4, 5, 12] Design and Optimization of Drugs predicts interactions and minimizes data bias and model generalizability in lab work.[6, 13] Clinical Experiments Improved efficiency and patient stratification Concerns about ethics and regulations.[8, 9, 14, 15] Customized Healthcare Customized treatments, better results Integration issues and data privacy.[10, 16]

Table. 1 Important Uses in Drug Discovery

Important Uses in Drug Discovery	The role and impact of AI/ML	References
Identification and Validation of the Target	Finding and validating pharmacological targets using the analysis of proteomics, genomes, and patient data	(17, 18)
Design and Screening of Molecules	utilizing patient information and molecular fingerprints to find novel applications for current medications	(5, 9, 17, 19, 20)
Estimating Toxicity and Efficacy	Reducing late-stage failures and forecasting ADME-Tox properties	(17, 21, 22)
Customized Healthcare	Patient stratification, treatment optimization, and response prediction	(17, 21, 23)

Using AI to Find Novel Drug Targets and Lead Compounds

Artificial intelligence is revolutionizing the drug discovery process by identifying new disease targets, reducing expenses and time, and accelerating the design and highly accurate screening of novel compounds.[24]

Key Applications of AI in Drug Development

1. Target Identification and Validation

AI models that use genomes, proteomics, and clinical data to identify new disease targets have made it possible to design structure-based medications for proteins that were previously inaccessible.[25] This boosts target selection confidence.[7, 13, 26]

2. Finding and Improving Lead Compounds

AI models and platforms like Mol Prophet and Deep Malaria enable faster lead compound prioritization and optimization.[7] [25]Researchers can now more easily create advanced drugs thanks to these tools, which can find possible leads in a matter of weeks.[13, 27]

3. Drug Repurposing and Polypharmacology

Artificial intelligence (AI) improves therapeutic efficacy in polypharmacology by targeting multiple proteins, [28, 29]whereas systematic AI-based repurposing discovers new uses for current drugs by mapping activity profiles across diverse targets.[24, 27]

Estimating the Safety and Efficacy of Drugs:

AI/ML models are revolutionizing drug efficacy and safety prediction, enabling early compound and risk identification,[22] accelerating development, and improving patient safety through advanced dataset analysis.[30]

How Drug Safety and Efficacy Are Predicted by AI/ML Models

Mechanisms and New Developments

Particularly for medication combinations and customized treatments, multimodal AI integrates structural, route, cell, and transcriptome data to provide more precise efficacy and safety predictions.[31] In order to enable personalized medicine and improved clinical decision-making, Causal ML calculates the impacts of individual treatments.[30] Explainable AI (XAI) builds trust by elucidating the prediction process, which is essential for clinical application and regulatory approval.[32, 33] Models can learn from a variety of patient populations and actual clinical outcomes when real-world data is integrated with them (such as EHRs and patient registries).[33-35]

Restrictions and Difficulties

Diversity and quality of data are essential; biased or subpar data might lower model reliability.[22, 36, 37] Clinical trust and regulatory approval depend on the interpretability of the model.[32, 36] Transparent reporting, bias reduction, and data privacy are ethical and legal factors.[33]

Improving Patient Recruitment and Clinical Trial Design

Advances in clinical trial design and patient recruitment—using digital platforms, artificial intelligence, and patient engagement—are critical to accelerating medical research, reducing costs, and ensuring diverse study populations.[38]

Creative Hiring Techniques

Machine learning and artificial intelligence:

AI-driven models, like deep learning and hybrid classification systems, are being used to identify eligible patients,[39] predict the success of recruitment, and enhance site selection despite concerns about bias and data privacy.[40-42]

Online Resources:

Online consent, patient matching platforms, and e-recruitment technologies have improved patient involvement, cost reduction, and recruitment since COVID-19; however, accessibility and transparency remain problems.[43, 44]

Frameworks and Optimal Techniques for Strategic Planning:

Comprehensive frameworks prioritize early planning, feasibility studies, and communication strategies to overcome recruiting barriers; [45]upstream interventions like protocol optimization and site selection are critical to success.[46, 47]

Design with the patient in mind:

Patient involvement in trial design enhances recruitment, retention, and the significance of results by identifying barriers,[48] adjusting protocols, and promoting diversity in recruitment.[49, 50]

AI in Dosage Individualization and Personalized Medicine:

AI is revolutionizing personalized medicine by analyzing enormous volumes of patient data to create precise treatment plans and drug dosages that maximize benefits and reduce side effects.[7]

How AI Customizes Integration of Drug Dosage Data:

AI systems use genetic, clinical, and lifestyle data to predict drug metabolism and response, increasing dosage accuracy and reducing prescription trial-and-error.[51, 52]

Pharmacogenomics: AI-powered genetic variation analysis reduces side effects and increases effectiveness by identifying the drugs and dosages that are most effective for each patient.[51, 53]

Adaptive Dosing: Machine learning algorithms dynamically adjust dosages based on real-time patient data (such as blood glucose and kidney function), especially for chronic diseases like diabetes and cancer.[54, 55]

Uses in Drug Discovery and Development and Delivery:

AI speeds up the process of finding new drug candidates and predicts how they will interact, which simplifies the development of personalized therapies.[7, 9, 56, 57]

3D Printed Dosage Forms: AI and 3D printing combine to produce customized medicine capsules with controlled release profiles that are tailored to each patient's requirements.[58]

Clinical Decision Support: AI-powered solutions that link to electronic health records provide real-time alerts about potential medication errors and promote safer prescription procedures.[56, 59]

Table. 2 Benefits and Challenges

Advantage/Difficulty	Description	References
Enhanced efficacy & safety	More effective medicines, fewer adverse reactions	(51-53, 56)
Reduced medication mistakes	Real-time notifications and adaptive dosing	(54, 56)
Data privacy & bias concerns	Need for comprehensive safeguards and equal access	(51, 52, 60, 61)
Regulatory and ethical hurdles	Ongoing need for clear guidelines and validation	(60, 61)

Developments in Gene and Cell Therapy

Advances in gene and cell therapy, including genome editing and delivery technologies, are allowing experimental treatments for several diseases to be approved.[62]

Important Technological Developments

Genome editing: By precisely modifying, adding, or removing genes, technologies such as CRISPR/Cas9, zinc finger nucleases,[62] and TALENs enable targeted therapy of cancer and genetic illnesses.[63, 64]

Gene Delivery Systems: The effectiveness and safety of delivering therapeutic genes to certain tissues have been enhanced using viral vectors (such as lentivirus and adeno-associated virus) and non-viral techniques (such as liposomes and nanoparticles).[65, 66]

Cell-Based Therapies: Cancer, blood problems, and neurological diseases are now being treated with engineered immune cells (such as CAR-T cells) and stem cell alterations.[67, 68]

Clinical Development and Uses

Globally, over 100 gene, cell, and RNA therapies are approved, addressing conditions like inherited blindness, hemophilia, and cancers,[64] while also advancing HIV treatment for durable viral suppression.[64, 65, 69]

Table. 3 Current Gene and Cell Therapy Approvals and Uses

Area of Disease	Example Therapies/Targets	Technology Used	References
Blindness that is inherited	AAV vector gene addition	Viral vector	(65, 67)
Hemophilia	AAV vector gene addition	Viral vector	(65, 69)
diseases of the blood (e.g., SCD)	HSC gene editing, lentiviral	Genome editing, viral	(67, 70)
Cancer	CAR-T cells, gene silencing	Cell therapy, CRISPR	(71, 72)
HIV	Engineered T/B cells, gene editing	Cell/gene therapy	(73, 74)

Obstacles and Prospects

Stakeholders must cooperate to resolve issues with affordability, safety, and effectiveness as well as ethical and legal worries about germline editing and long-term effects in order to increase access.[64, 69, 75]

Therapeutic Development Using CRISPR/Cas9 Gene Editing Applications:

CRISPR/Cas9 gene editing is transforming therapeutic development by fixing genetic mutations and curing diseases like cancer and rare genetic disorders, despite delivery methods and off-target effects still being problems.[76, 77]

Targets for Disease and Therapeutic Uses

CRISPR/Cas9 is being used to repair disease-causing mutations, disrupt genes, and produce immune cells for cancer immunotherapy.[78] Although both in vivo and ex vivo techniques are being researched, ex vivo techniques predominate in clinical trials.[79, 80]

Delivery Methods and Difficulties:

Using viral vectors, non-viral nanoparticles, and direct injections to safely and efficiently deliver CRISPR/Cas9 components to target cells is challenging.[81] In vivo administration is crucial for disease treatment.[76, 79]

Effects Off-Target and Safety Issues:
High-fidelity Cas9 variants, improved delivery systems, and inadvertent modifications to guide RNA design all lessen risks, [82]but more work is needed before broad clinical application can take place.[79, 80]

Tissue engineering and stem cell therapy in regenerative medicine:
Stem cell therapy and tissue engineering are crucial regenerative medicine techniques that can be used to replace or repair damaged tissues and organs as well as offer new treatments for diseases and injuries that were previously incurable.[83]

Important Methods in Stem Cell Therapy for Regenerative Medicine:
Adult and pluripotent stem cells, such as induced pluripotent stem cells (iPSCs), are used in stem cell therapy to promote tissue replacement or repair in damaged areas,[84] thereby treating neurodegenerative diseases, heart disease, diabetes, and spinal cord injuries.[85-87]

Tissue Engineering:
Tissue engineering employs stem cells, biomaterial scaffolds, and bioactive chemicals to create viable tissue constructions for organ replacement and repair,[83] thanks to advancements in scaffold design and 3D bioprinting.[88, 89]

Current Developments and Uses of Extracellular Vesicles (EVs):
Because stem cell-derived EVs can promote tissue healing and are less immunogenic and safer than whole-cell therapies, they are gaining popularity.[90-92]

Complex and Customized Tissues:
3D organoids and altered tissues are being developed for personalized treatment, transplantation, and drug testing.[93, 94]

Applications in Veterinary Medicine and Dentistry:
Stem cell therapies are being researched in veterinary medicine and dental tissue engineering, with encouraging outcomes for both human and animal health.[95, 96]

Obstacles and Prospects
Among the challenges are risks to efficacy and safety, ethical and legal quandaries, and technological challenges.[93, 94] Although engineered cell products and biomaterial developments present potential remedies, [83]more clinical testing and standardized procedures are needed for broader clinical acceptance.[88, 97]

Biopharmaceuticals, such as vaccines and monoclonal antibodies
Biopharmaceuticals, like mAbs and vaccines, have revolutionized medicine by providing targeted medications for a range of diseases, treating cancer, autoimmune disorders, and combating antibiotic resistance.[98]

Biopharmaceutical Monoclonal Antibodies (mAbs) Types and Uses:
Numerous conditions, such as cancer, chronic inflammatory diseases, transplantation, infectious diseases, and cardiovascular disorders, are treated with monoclonal antibodies (mAbs).[99, 100] They are made to be safer and more effective, and they are very specific.[101, 102]

Vaccines: Among the vaccines that prevent infectious diseases, immunocompromised vaccines that involve antibody-antigen interactions are increasingly being studied for therapeutic applications.[98, 103]

Antibody-Drug Conjugates (ADCs): which combine cytotoxic pharmaceuticals and monoclonal antibodies (mAbs) for targeted cancer therapy, include a number of FDA-approved drugs as well as others that are currently under development.[104]

Mechanisms of Action
By binding antigens, mAbs, which are impacted by antibody structure and glycosylation, change immune responses and result in cell death. Vaccines that stimulate the immune system enhance immune complex responses.[99, 103]

Developments in Manufacturing and Analysis
For safety, efficacy, and consistency, mAb production necessitates strict quality control using plant-based expression systems,[105] sophisticated analytical

methods, and regulatory frameworks like Quality-by-Design and cGMP.[106]

Personalized medicine and pharmacogenomics
Pharmacogenomics drives personalized medicine and assists the medical community in shifting from a "one-size-fits-all" approach to safer,[107] more precise, and more effective treatments by tailoring drug regimens to each patient's distinct genetic makeup.[108, 109]

Mechanisms and Principles
Pharmacogenomics examines the effects of genetic variations in drug-metabolizing enzymes, transporters, and receptors on drug efficacy and side effect risk.[110] Whole genome and other "-omics" data are incorporated for a comprehensive understanding of patient variability.[111, 112]

Impact and Clinical Uses
In personalized medicine, pharmacogenomic testing is improving outcomes in oncology, psychiatry, and cardiovascular disease.[113] This strategy has FDA approval, and Pharm and other resources provide helpful advice.[110, 114, 115]

Technologies for Digital Health
Digital health technologies are revolutionizing healthcare through the integration of wearables, telemedicine, mobile apps, artificial intelligence, and electronic health records. Despite the challenges they pose, they also enhance efficiency, accessibility, and customization.[116]

Types of Digital Health Technologies and Their Uses: Remote diagnosis, treatment, and follow-up are made possible by telemedicine and remote monitoring, which is particularly helpful for elderly or rural populations as well as during pandemics.[116-118]

Wearables and Mobile Health (mHealth): Monitor health indicators, assist in managing chronic conditions, and enable patients to take care of themselves[119]

Big Data and Artificial Intelligence: Boost public health monitoring, customize therapies, and improve diagnostics.[118, 119]

Digital Tools for Clinical Trials: Enable patient-centered research and practical data collecting.[120]

Future Direction
The future of pharmaceutical sciences depends on incorporating blockchain, AI, gene editing, and digital health into clinical, regulatory, and manufacturing procedures. Priorities include safer treatments, ethical application, and transparency. Sustainable practices and safe blockchain-based supply chains will increase efficiency and patient-centeredness.

Result & Discussion
The application of new technology in the pharmaceutical sciences has significantly improved patient care, drug discovery, and manufacturing processes. AI and ML have accelerated clinical trials, personalized medicine, and drug development, while pharmacogenomics has created safer treatments. Although gene and cell therapies have made significant clinical progress, concerns about cost, safety, and delivery methods still exist. Digital health tools are improving patient monitoring and medication adherence, while green analytical chemistry and regenerative medicine promote sustainability and quality. Blockchain technology is making the pharmaceutical supply chain more transparent and safer.

CONCLUSION
Thanks to new technologies, the pharmaceutical sciences are developing into innovative, patient-centered, and productive domains. Future developments in artificial intelligence, machine learning, pharmacogenomics, gene and cell therapies, digital health technologies, green analytical chemistry, continuous manufacturing, regenerative medicine, and blockchain will make pharmaceutical sciences more predictive, transparent, and equitable.

REFERENCES
Pasupuleti MK. AI-Driven Bioinformatics: Transforming Genomics, Gene Editing, and Personalized Medicine. International Journal of Academic and Industrial Research Innovations(IJAIRI). 2025.

Dixit S, Kumar A, Srinivasan K, Durai P, Vincent R, Krishnan NR, et al. Advancing genome editing with artificial intelligence: opportunities, challenges, and future directions. Frontiers in Bioengineering and Biotechnology. 2024;11.

Srivastav AK, Mishra M, Lillard J, Singh R. Transforming Pharmacogenomics and CRISPR Gene Editing with the Power of Artificial Intelligence for Precision Medicine. Pharmaceutics. 2025;17.

Wang Y, Yang X, Byrne R, Schneider G, Yang S-Y. Concepts of Artificial Intelligence for Computer-Assisted Drug Discovery. Chemical reviews. 2019.

Cerchia C, Lavecchia A. New avenues in artificial-intelligence-assisted drug discovery. Drug discovery today. 2023:103516.

Jiménez-Luna J, Grisoni F, Weskamp N, Schneider G. Artificial intelligence in drug discovery: recent advances and future perspectives. Expert Opinion on Drug Discovery. 2021;16:949-59.

Vora L, Gholap A, Jetha K, Thakur R, Solanki H, Chavda V. Artificial Intelligence in Pharmaceutical Technology and Drug Delivery Design. Pharmaceutics. 2023;15.

Sanjay KD, Gadekar P, Patil KVT. Transforming Drug Discovery: The Impact of Artificial Intelligence and Machine Learning from Initial Screening to Clinical Trials. International Journal for Research in Applied Science and Engineering Technology. 2024.

Artificial Intelligence (AI) Applications in Drug Discovery and Drug Delivery: Revolutionizing Personalized Medicine. Pharmaceutics. 2024;16.

Qi X, Zhao Y, Qi Z, Hou S, Chen J. Machine Learning Empowering Drug Discovery: Applications, Opportunities and Challenges. Molecules. 2024;29.

Vişan A, Neguţ I. Integrating Artificial Intelligence for Drug Discovery in the Context of Revolutionizing Drug Delivery. Life. 2024;14.

Parvathaneni M, Awol A, Kumari M, Lan K, Lingam M. Application of Artificial Intelligence and Machine Learning in Drug Discovery and Development. Journal of Drug Delivery and Therapeutics. 2023.

Han R, Yoon H, Kim G, Lee H, Lee Y. Revolutionizing Medicinal Chemistry: The Application of Artificial Intelligence (AI) in Early Drug Discovery. Pharmaceuticals. 2023;16.

Kolluri S, Lin J, Liu R, Zhang Y, Zhang W. Machine Learning and Artificial Intelligence in Pharmaceutical Research and Development: a Review. The AAPS Journal. 2022;24.

Niazi S. The Coming of Age of AI/ML in Drug Discovery, Development, Clinical Testing, and Manufacturing: The FDA Perspectives. Drug Design, Development and Therapy. 2023;17:2691-725.

Rehman A, Li M, Wu B, Ali Y, Rasheed S, Shaheen S, et al. Role of Artificial Intelligence in Revolutionizing Drug Discovery. Fundamental Research. 2024.

Vamathevan J, Clark D, Czodrowski P, Dunham I, Ferran E, Lee G, et al. Applications of machine learning in drug discovery and development. Nature Reviews Drug Discovery. 2019;18:463-77.

Dhudum R, Ganeshpurkar A, Pawar A. Revolutionizing Drug Discovery: A Comprehensive Review of AI Applications. Drugs and Drug Candidates. 2024.

Hadi MU, Khan S, Gondal TM, Alam T, Yan H, Irfan M, et al. AI in drug discovery and its clinical relevance. Heliyon. 2023;9.

Chen S, Chen W, Liu X, Zhang S. Artificial intelligence for drug discovery: Resources, methods, and applications. Molecular Therapy Nucleic Acids. 2023;31:691-702.

Dara S, Dhamercherla S, Jadav S, Babu C, Ahsan M. Machine Learning in Drug Discovery: A Review. Artificial Intelligence Review. 2021;55:1947-99.

Ambreen S, Umar M, Noor A, Jain H, Ali R. Advanced AI and ML frameworks for transforming drug discovery and optimization: With innovative insights in polypharmacology, drug repurposing, combination therapy and nanomedicine. European journal of medicinal chemistry. 2024;284:117164.

Vemula D, Jayasurya P, Sushmitha V, Kumar YN, Bhandari V. CADD, AI and ML in Drug Discovery: A Comprehensive Review. European journal of pharmaceutical sciences : official journal of the European Federation for Pharmaceutical Sciences. 2022:106324.

Li G, Lin P, Wang K, Gu C, Kusari S. Artificial intelligence-guided discovery of anticancer lead compounds from plants and associated microorganisms. Trends in cancer. 2021.

Batool M, Ahmad B, Choi S. A Structure-Based Drug Discovery Paradigm. International Journal of Molecular Sciences. 2019;20.

Pun F, Ozerov I, Zhavoronkov A. AI-powered therapeutic target discovery. Trends in pharmacological sciences. 2023.

Subramanian N, Maignan N, Tieo G, Papazian D, Dawe J, Georges M, et al. 103P Using AI to break new ground in oncological drug discovery: Rapid identification of novel targets and polypharmacological compounds for effective liposarcoma treatment. ESMO Open. 2024.

Cichońska A, Ravikumar B, Rahman R. AI for targeted polypharmacology: The next frontier in drug discovery. Current opinion in structural biology. 2024;84:102771.

Tanoli Z, Vähä-Koskela M, Aittokallio T. Artificial intelligence, machine learning, and drug repurposing in cancer. Expert Opinion on Drug Discovery. 2021;16:977-89.

Feuerriegel S, Frauen D, Melnychuk V, Schweisthal J, Hess K, Curth A, et al. Causal machine learning for predicting treatment outcomes. Nature medicine. 2024;30 4:958-68.

Zitnik M, John B, Su X, Ullanat V, Clegg L, Ho N, et al. Multimodal AI predicts clinical outcomes of drug combinations from preclinical data. ArXiv. 2025.

Vo T, Nguyen N, Kha Q, Le N. On the road to explainable AI in drug-drug interactions prediction: A systematic review. Computational and Structural Biotechnology Journal. 2022;20:2112-23.

Prelaj A, Galli E, Miskovic V, Pesenti M, Viscardi G, Pedica B, et al. Real-world data to build explainable trustworthy artificial intelligence models for prediction of immunotherapy efficacy in NSCLC patients. Frontiers in Oncology. 2023;12.

Arun N, Ravichandran K. AI Models for Predicting Drug Efficacy and Toxicity to Accelerate Personalized Medicine and Drug Discovery. 2024 4th International Conference on Soft Computing for Security Applications (ICSCSA). 2024:283-90.

Moingeon P, Chenel M, Rousseau C, Voisin E, Guedj M. Virtual patients, digital twins and causal disease models: paving the ground for in silico clinical trials. Drug discovery today. 2023:103605.

Tiwari P, Pal R, Chaudhary M, Nath R. Artificial intelligence revolutionizing drug development: Exploring opportunities and challenges. Drug Development Research. 2023;84:1652-63.

Bhattacharjee A, Kumar A, Ojha P, Kar S. Artificial intelligence to predict inhibitors of drug-metabolizing enzymes and transporters for safer drug design. Expert Opinion on Drug Discovery. 2025;20:621-41.

Schepps MA, Wong WK, Austin M, Anisimov V. Optimizing Patient Recruitment in Global Clinical Trials using Nature-Inspired Metaheuristics. Statistics in Biopharmaceutical Research. 2024;17:87-101.

Kumar CUO, Singh I, Marappan S. Optimizing Patient Recruitment for Clinical Trials: A Hybrid Classification Model and Game-Theoretic Approach for Strategic Interaction. IEEE Access. 2024;12:10254-80.

Reddy VP, Haseena S. A HYBRID CLASSIFICATION AND GAME-THEORETIC STRATEGY FOR OPTIMIZING PATIENT RECRUITMENT IN CLINICAL TRIALS. International Journal of Engineering Research and Science & Technology. 2025.

Lu X, Yang C, Liang L, Hu G, Zhong Z, Jiang Z. Artificial intelligence for optimizing recruitment and retention in clinical trials: a scoping review. Journal of the American Medical Informatics Association : JAMIA. 2024;31:2749-59.

Ranjith, Manvitha E, Vithal CL, Payarda CH. OPTIMIZING PATIENT RECRUITMENT FOR CLINICAL TRIALS: A HYBRID CLASSIFICATION MODEL AND GAME-THEORETIC APPROACH FOR STRATEGIC INTERACTION. Industrial Engineering Journal. 2024.

Brøgger-Mikkelsen M, Ali Z, Zibert J, Andersen A, Thomsen S. Online Patient Recruitment in Clinical Trials: Systematic Review and Meta-Analysis. Journal of Medical Internet Research. 2020;22.

Bikou A, Deligianni E, Dermiki-Gkana F, Liappas N, Teriús-Padrón JG, Jaunsarás MEB, et al. Improving Participant Recruitment in Clinical Trials: Comparative Analysis of Innovative Digital Platforms. Journal of Medical Internet Research. 2024;26.

Huang G, Bull J, McKee KJ, Mahon E, Harper B, Roberts J. Clinical trials recruitment planning: A proposed framework from the Clinical Trials Transformation Initiative. Contemporary clinical trials. 2018;66:74-9.

Zahren C, Harvey S, Weekes L, Bradshaw C, Butala R, Andrews J, et al. Clinical trials site recruitment optimisation: Guidance from Clinical Trials: Impact and Quality. Clinical Trials (London, England). 2021;18:594-605.

Bertram W, Bertram W, Moore A, Wylde V, Wylde V, Gooberman-Hill R, et al. Optimising recruitment into trials using an internal pilot. Trials. 2019;20.

Elmer M, Karantza V, Vichnin M, Aktan G, Powell V. Leveraging patient engagement to optimize a phase 3 clinical trial design, study participation and recruitment for women diagnosed with triple-negative breast cancer (TNBC). Journal of Clinical Oncology. 2022.

Tong A, Scholes-Robertson N, Hawley C, Viecelli A, Carter S, Levin A, et al. Patient-centred clinical trial design. Nature Reviews Nephrology. 2022;18:514-23.

Whybrow P, Pickard R, Hrisos S, Rapley T. Equipoise across the patient population: optimising recruitment to a randomised controlled trial. Trials. 2017;18.

Nwankwo EI, Emeihe EV, Ajegbile MD, Olaboye JA, Maha CC. AI in personalized medicine: Enhancing drug efficacy and reducing adverse effects. International Medical Science Research Journal. 2024.

Taherdoost H, Ghofrani A. AI's role in revolutionizing personalized medicine by reshaping pharmacogenomics and drug therapy. Intelligent Pharmacy. 2024.

Patel YA, Narkhede K, Prajapati A, Narkhede S, Luhar S. AI-Driven Pharmacogenomics: The Future of Personalized Medicine. Asian Journal of Pharmacy and Technology. 2025.

Pandey M. Development of predictive models for personalized drug dosing in pediatrics. Journal of Health Physiotherapy and Orthopaedics. 2025.

Ahmed H, Hamad S, Shedeed H, Hussein A. Enhanced Deep Learning Model for Personalized Cancer Treatment. IEEE Access. 2022;10:106050-8.

Igwama GT, Nwankwo EI, Emeihe EV, Ajegbile MD. The role of AI in optimizing drug dosage and reducing medication errors. International Journal of Biology and Pharmacy Research Updates. 2024.

Li Y, Zhang H, Anderson K, Li S, Zhu R. AI in Pharma for Personalized Sequential Decision-Making: Methods, Applications and Opportunities. ArXiv. 2023;abs/2311.18725.

Hu J, Wan J, Xi J, Shi W, Qian H. AI-driven design of customized 3D-printed multi-layer capsules with controlled drug release profiles for personalized medicine. International journal of pharmaceutics. 2024:124114.

Chalasani S, Syed J, Ramesh M, Patil V, Kumar TMP. Artificial intelligence in the field of pharmacy practice: A literature review. Exploratory Research in Clinical and Social Pharmacy. 2023;12.

Udegbe FC, Ebulue OR, Ebulue CC, Ekesiobi CS. AI'S IMPACT ON PERSONALIZED MEDICINE: TAILORING TREATMENTS FOR IMPROVED HEALTH OUTCOMES. Engineering Science & Technology Journal. 2024.

Babawarun O, Olorunsogo T, Okolo CA. A comprehensive review of AI applications in personalized medicine. International Journal of Science and Research Archive. 2024.

Maeder M, Gersbach C. Genome-editing Technologies for Gene and Cell Therapy. Molecular Therapy. 2016;24:430-46.

Chancellor D, Barrett D, Nguyen-Jatkoe L, Millington S, Eckhardt F. The State of Cell and Gene Therapy in 2023. Molecular therapy : the journal of the American Society of Gene Therapy. 2023.

Cetin B, Erendor F, Eksi Y, Şanlioğlu A, Sanlioglu S. Gene and cell therapy of human genetic diseases: Recent advances and future directions. Journal of Cellular and Molecular Medicine. 2024;28.

Liu F, Li R, Zhu Z, Yang Y, Lu F. Current developments of gene therapy in human diseases. MedComm. 2024;5.

Danaeifar M. Recent advances in gene therapy: genetic bullets to the root of the problem. Clinical and Experimental Medicine. 2022;23:1107-21.

Giommetti A, Papanikolaou E. Advancements in Hematopoietic Stem Cell Gene Therapy: A Journey of Progress for Viral Transduction. Cells. 2024;13.

Yong SB, Chung J, Song Y, Kim Y-H. Recent challenges and advances in genetically-engineered cell therapy. Journal of Pharmaceutical Investigation. 2017;48:199-208.

Dunbar C, High K, Joung J, Kohn D, Ozawa K, Sadelain M. Gene therapy comes of age. Science. 2018;359.

Bueren J, Quintana-Bustamante O, Almarza E, Navarro S, Río P, Segovia J, et al. Advances in the gene therapy of monogenic blood cell diseases. Clinical Genetics. 2019;97:102-89.

Abas MDM, Asri MFM, Yusafawi NAS, Rosman NAZ, Baharudin NAZ, Taher M, et al. Advancements of gene therapy in cancer treatment: A comprehensive review. Pathology, research and practice. 2024;261:155509.

Cesur-Ergün B, Demir-Dora D. Gene therapy in cancer. The Journal of Gene Medicine. 2023;25.

Gonçalves GAR, Paiva R. Gene therapy: advances, challenges and perspectives. Einstein. 2017;15:369-75.

Kitawi R, Ledger S, Kelleher A, Ahlenstiel C. Advances in HIV Gene Therapy. International Journal of Molecular Sciences. 2024;25.

Rouce R, Porteus M. Cell and gene therapy accessibility. Science. 2024;385:475-.

Wang S-W, Gao C, Zheng Y-M, Yi L, Lu J-C, Huang X-Y, et al. Current applications and future perspective of CRISPR/Cas9 gene editing in cancer. Molecular Cancer. 2022;21.

Guo N, Liu J, Li W, Yushui, Fu D. The power and the promise of CRISPR/Cas9 genome editing for clinical application with gene therapy. Journal of Advanced Research. 2021;40:135-52.

Li Y, Glass Z, Huang M, Chen Z-Y, Xu Q. Ex vivo cell-based CRISPR/Cas9 genome editing for therapeutic applications. Biomaterials. 2020;234:119711.

Li T, Yang Y, Qi H, Cui W, Zhang L, Fu X, et al. CRISPR/Cas9 therapeutics: progress and prospects. Signal Transduction and Targeted Therapy. 2023;8.

Bhattacharjee G, Gohil N, Khambhati K, Mani I, Maurya R, Karapurkar J, et al. Current approaches in CRISPR-Cas9 mediated gene editing for biomedical and therapeutic applications. Journal of controlled release : official journal of the Controlled Release Society. 2022.

Mout R, Ray M, Lee Y, Scaletti F, Rotello V. In Vivo Delivery of CRISPR/Cas9 for Therapeutic Gene Editing: Progress and Challenges. Bioconjugate chemistry. 2017;28 4:880-4.

Guo C, Xiaoteng, Gao F, Guo Y. Off-target effects in CRISPR/Cas9 gene editing. Frontiers in Bioengineering and Biotechnology. 2023;11.

Ratna AP, Ginting KH, Subroto I, Santoso A, Purwoko RY. Regenerative Medicine: Tissue Engineering and Stem Cell Therapy. Join: Journal of Social Science. 2024.

Kasarla RR, Pathak L. " Stem Cell Therapy In Regenerative Medicine And Tissue Engineering ". Journal of Stem Cell Research. 2022.

Dinh NTH, Thanh LN, Nguyen Q, Hoang V, Le QD, Dao LTM, et al. Tissue Engineering and Regenerative Medicine: Perspectives and Challenges. MedComm. 2025;6.

Bharti S, Kumar A. Correlation in Stem Cell Technology, Tissue Engineering, and Regenerative Medicine. Regenerative Engineering and Translational Medicine. 2025.

Mahla R. Stem Cells Applications in Regenerative Medicine and Disease Therapeutics. International Journal of Cell Biology. 2016;2016.

Shafiq M, Ali O, Han S-B, Kim D-H. Mechanobiological Strategies to Enhance Stem Cell Functionality for Regenerative Medicine and Tissue Engineering. Frontiers in Cell and Developmental Biology. 2021;9.

Chen Y, Huang H, Li G, Yu J, Fang F, Qiu W. Dental-derived mesenchymal stem cell sheets: a prospective tissue engineering for regenerative medicine. Stem Cell Research & Therapy. 2022;13.

Tsiapalis D, O'Driscoll L. Mesenchymal Stem Cell Derived Extracellular Vesicles for Tissue Engineering and Regenerative Medicine Applications. Cells. 2020;9.

Arbade G, Jose JV, Gulbake A, Kadam S, Kashte S. From stem cells to extracellular vesicles: a new horizon in tissue engineering and regenerative medicine. Cytotechnology. 2024;76 4:363-401.

Dong Y-J, Hu J, Song Y-T, Gao Y-Y, Zheng M, Zou C-Y, et al. Extracellular Vesicles from Urine-derived Stem Cell for Tissue Engineering and Regenerative Medicine. Tissue engineering Part B, Reviews. 2023.

Harris A, Walker M, Gilbert F. Ethical and regulatory issues of stem cell-derived 3-dimensional organoid and tissue therapy for personalised regenerative medicine. BMC Medicine. 2022;20.

Han H, Chen B-T, Liu Y, Wang Y, Xing L, Wang H, et al. Engineered stem cell-based strategy: A new paradigm of next-generation stem cell product in regenerative medicine. Journal of controlled release : official journal of the Controlled Release Society. 2023.

El-Husseiny H, Mady E, Helal M, Tanaka R. The Pivotal Role of Stem Cells in Veterinary Regenerative Medicine and Tissue Engineering. Veterinary Sciences. 2022;9.

Botelho J, Cavacas M, Machado V, Mendes J. Dental stem cells: recent progresses in tissue engineering and regenerative medicine. Annals of Medicine. 2017;49:644-51.

Kwon SG, Kwon YW, Lee T, Park G, Kim J. Recent advances in stem cell therapeutics and tissue engineering strategies. Biomaterials Research. 2018;22.

Wang X-Y, Wang B, Wen Y. From therapeutic antibodies to immune complex vaccines. NPJ Vaccines. 2019;4.

Ayana MT. The role of monoclonal antibodies in therapy and vaccine developments. International Journal of Immunology Research. 2023.

Sivaccumar J, Sandomenico A, Vitagliano L, Ruvo M. Monoclonal antibodies: A prospective and retrospective view. Current medicinal chemistry. 2020.

Crescioli S, Kaplon H, Chenoweth A, Wang L, Visweswaraiah J, Reichert J. Antibodies to watch in 2024. mAbs. 2024;16.

Kim SJ, Park Y, Hong H. Antibody engineering for the development of therapeutic antibodies. Molecules and cells. 2005;20 1:17-29.

La Guidara C, Adamo R, Sala C, Micoli F. Vaccines and Monoclonal Antibodies as Alternative Strategies to Antibiotics to Fight Antimicrobial Resistance. International Journal of Molecular Sciences. 2024;25.

Pettinato M. Introduction to Antibody-Drug Conjugates. Antibodies. 2021;10.

Carrara S, Ulitzka M, Grzeschik J, Kornmann H, Hock B, Kolmar H. From cell line development to the formulated drug product: The art of manufacturing therapeutic monoclonal antibodies. International journal of pharmaceutics. 2020:120164.

Diamos A, Hunter J, Pardhe M, Rosenthal S, Sun H, Foster B, et al. High Level Production of Monoclonal Antibodies Using an Optimized Plant Expression System. Frontiers in Bioengineering and Biotechnology. 2020;7.

Cecchin E, Stocco G. Pharmacogenomics and Personalized Medicine. Genes. 2020;11.

Rithe E, Dighade S, Bhamburkar S, Mangwani R, Raut A, Pohane A. Pharmacogenomics and Personalized Medicine: Transforming Drug Treatment Paradigms. International Journal of Innovative Science and Research Technology. 2025.

P PG, Shivam K, Mohan M, Prasad J. A Review: Pharmacogenomics and Personalized Medicine. International Journal for Research in Applied Science and Engineering Technology. 2023.

Sadee W, Wang D, Hartmann K, Toland A. Pharmacogenomics: Driving Personalized Medicine. Pharmacological Reviews. 2023;75:789-814.

Raj G. Pharmacogenetics, Pharmacogenomics, and Personalized Medicine. Introduction to Basics of Pharmacology and Toxicology. 2019.

Dash B, Shireen M, Pushpendra, Kumar S, Goel A, Semwal P, et al. A Comprehensive Review: Pharmacogenomics and Personalized Medicine Customizing Drug Therapy Based on Individual Genetics Profiles. Zhongguo ying yong sheng li xue za zhi = Zhongguo yingyong shenglixue zazhi = Chinese journal of applied physiology. 2024;40.

Pharmacogenomics and personalized medicine: A Descriptive study of current trends and future perspective. European Journal of Molecular & Clinical Medicine. 2023.

McMahon F, Insel T. Pharmacogenomics and Personalized Medicine in Neuropsychiatry. Neuron. 2012;74:773-6.

Feng F, Shen B, Mou X, Li Y, Li H. Large-scale pharmacogenomic studies and drug response prediction for personalized cancer medicine. Journal of genetics and genomics = Yi chuan xue bao. 2021.

Yeung A, Torkamani A, Butte A, Glicksberg B, Schuller B, Rodriguez B, et al. The promise of digital healthcare technologies. Frontiers in Public Health. 2023;11.

Mitchell M, Kan L. Digital Technology and the Future of Health Systems. Health Systems & Reform. 2019;5:113-20.

Senbekov M, Saliev T, Bukeyeva Z, Almabayeva A, Zhanaliyeva M, Aitenova N, et al. The Recent Progress and Applications of Digital Technologies in Healthcare: A Review. International Journal of Telemedicine and Applications. 2020;2020.

Chen C, Ding S, Wang J. Digital health for aging populations. Nature Medicine. 2023;29:1623-30.

Mittermaier M, Venkatesh K, Kvedar J. Digital health technology in clinical trials. NPJ Digital Medicine. 2023;6.