Journal of Digital Health
https://ojs.luminescience.cn/JDH

LUMINESCIENCE
https://luminescience.cn/

Review Article

Innovation management in AI advancement: Revolutionizing health system and biopharma

Sabeen Khaliq[*] Konstantin Koshechkin

Department of Public Health, I.M. Sechenov First Moscow State Medical University, Trubetskaya St. 8/2, 119991 Moscow, Russian Federation

*Correspondence: Sabeen Khaliq, Email: sabeenkhaliq430@gmail.com

Abstract: The integration of advanced technologies is reshaping the healthcare and biopharma industries and requires effective innovation management frameworks to leverage their potential while fully addressing associated risks. This literature review explores the global landscape of AI-driven innovation in the healthcare and biopharma, examining strategies, challenges and future directions. Technological applications are revolutionizing the pharmaceutical value chain by accelerating drug discovery and development, optimizing manufacturing processes and enhancing patient care delivery. For instance, AI-assisted drug development has reduced the time for candidate identification from years to just a few months, as demonstrated by the DSP-1181 project. Healthcare organizations employ statistical and symbolic methods to improve operational efficiency and patient outcomes. Despite promising advancements, significant challenges persist, including regulatory approval complexities, transparency and validation of algorithms, intellectual property protection, and ethical concerns such as data accuracy and bias. The responsibility for autonomous systems introduces additional difficulties in ownership and accountability. Successful adoption requires strategic planning for technology deployment alongside compliance with evolving regulatory and international standards. This review synthesizes current trends while identifying gaps in implementation. It provides structured insights for researchers, practitioners and policymakers.

Keywords: Artificial intelligence, Innovation management, Healthcare, Biopharma, Precision medicine

Introduction

Innovation management is essential for advancing the development and application of technologies within the healthcare and biopharma sectors. Defined as the systematic planning, development and implementation of new ideas, products and processes, innovation management ensures that novel technologies are translated into effective real-world solutions. The integration of cutting-edge technologies into life sciences is transforming how medicines are discovered, developed and delivered, enabling more personalized, efficient and effective treatments [1].

Recent trends indicate that the global market for AI in healthcare is projected to grow from USD 11 billion in 2021 to over USD 188 billion by 2030, highlighting the

Received: Jun.18, 2025; Revised: Jul.9, 2025; Accepted: Jul.14, 2025, Published: Jul.22, 2025

DOI: https://doi.org/10.55976/jdh.42025141429-38

urgent need to manage such innovations strategically. This progress is driven by collaborative networks that bring together expertise from academia, industry and regulatory bodies, creating an ecosystem that accelerates innovation while addressing scientific, economic and regulatory challenges.

Precision medicine, a rapidly growing subfield, refers to the customization of healthcare based on individual genetic, environmental and lifestyle factors and is one of the key areas being transformed by AI-driven innovation. Effective management of these innovations ensures that technological advancements lead to improved patient outcomes, streamlined operations and sustainable growth in the healthcare and biopharmaceutical industries [2].

This review highlights the key strategies and frameworks for managing innovation in this rapidly evolving field and emphasizes their impact on drug development, clinical care and global health. The analysis further identifies gaps in current innovation practices and proposes actionable strategies to enhance the integration and governance of AI technologies into the health and biopharma domains.

To ensure a comprehensive and balanced review, a structured literature search was conducted across four primary academic databases: PubMed, Scopus, Web of Science and IEEE Xplore. The search covered literature published between 2015 and 2025 and focussed on peer-reviewed articles in English. Search terms included "AI in healthcare", "biopharma innovation", "precision medicine", "AI governance" and "innovation management." Inclusion criteria required that articles directly relate to the application, governance or impact of AI technologies in the healthcare or pharmaceutical domains. Exclusion criteria filtered out non-peer-reviewed sources, editorial opinions and studies not involving healthcare or drug development. Over 120 articles were reviewed and the results were organized thematically based on their relevance to the core dimensions of innovation management (strategy, technology, ethics, collaboration). The structured search and article selection process is summarized in Table 1.

Table 1. Methodology summary of literature review

Component	Description
Databases Searched	PubMed, Scopus, Web of Science, IEEE Xplore
Keywords Used	"AI in healthcare", "biopharma innovation", "precision medicine" "AI governance" and "innovation management."
Time Frame	2015–2025
Inclusion Criteria	Peer-reviewed, English language, healthcare/biopharma context
Exclusion Criteria	Non-peer-reviewed, editorial opinions, non-English, unrelated to healthcare/biopharma
Total Articles Reviewed	120+ articles

Role of AI in healthcare

Innovations in technologies are changing the health and healthcare system for the better by enabling more individualized treatment, greater diagnostic accuracy and increased efficiency in clinical workflows [3]. Advanced computing systems can now process large datasets that include a patient's genomic analysis, medical history and lifestyle information to develop customized treatment strategies that significantly improve therapeutic outcomes and reduce the chances of negative side effects. This shift towards precision medicine is supported by the capacity of automated systems to make sense of intricate medical data and highlights a major change in the patient's journey [4]. For example, AI-based imaging tools such as Google's DeepMind have demonstrated over 90% accuracy in detecting over 50 types of eye diseases from retinal scans, outperforming some expert clinicians. Additionally, natural language processing (NLP) algorithms are now streamlining clinical documentation and reducing the administrative burdens on physicians.

Various studies have also highlighted the impact of evolving technologies on the effectiveness of the healthcare system. For example, the functionality of digital technologies has resulted in enhanced medical imaging, real-time patient monitoring and clinical documentation. These tools do not replace healthcare professionals, but rather enhance their capabilities and efficiency. As a result, the synergy between human decision-making and machine accuracy becomes possible [5]. However, despite these advancements, challenges remain. Many AI algorithms are trained on biased or incomplete datasets, leading to disparities in diagnoses or treatment outcomes for underrepresented populations. Resource limitations and a lack of AI infrastructure in low- and middle-income countries also limit the impact of these technologies on a broad scale. AI-driven programs are improving the interpretation of diagnostic images, predictive disease modeling and genetic analysis. [6].

Fu's publication in the European Journal of Human Genetics suggests that medical modalities, genomics and clinical data are being incorporated into more advanced models that are now helping to improve diagnostic accuracy across all medical specialities. These systems that integrate a variety of data sets, mark a significant transformation in patient care and medical head diagnosis and treatment and enpower clinicians to make well-informed decisions and to develop individualized treatment approaches [7].

AI-driven innovation in biopharma: drug discovery and development

The pharmaceutical industry is currently undergoing a major transformation with the introduction of Artificial Intelligence (AI), which analyzes biological and chemical information to speed up drug discovery and development. AI-driven models for predicting drug targets, toxicity and pharmacokinetics are estimates that significantly shorten the development of early-stage drug contender, while minimizing time and cost [7]. Techniques of generative AI, such as variational autoencoders and generative adversarial networks, assist in the design of novel compounds. Deep learning also reinforces the prediction of protein structures for more accurate structure-based drug design [8]. For example, AlphaFold, developed by DeepMind, has accurately predicted over 200 million protein structures, accelerating research in biopharma. These capabilities drastically reduce experimental costs and enable more targeted therapeutic development.

The effects of AI go beyond formulation, discovery, manufacturing and clinical trials. In predictive analytics, trial design and patient recruitment are conducted more efficiently, improving trial outcomes, while AI automation boosts quality control in supply chain management (SCM) and manufacturing workflows [9]. A notable example includes the AI-designed molecule DSP-1181, developed for obsessive-compulsive disorder, which moved from discovery to clinical trials in just 12 months—a process that usually takes 4–5 years. Insilico Medicine has rapidly identified new targets and experimented with drug candidates, proving that AI drastically shortens development timelines [10]. These breakthroughs lead to scalable and more economically affordable pharmaceutical production. The role of AI in the drug development pipeline is illustrated in Figure 1.

The integration of AI technology additionally aids in drug repurposing and expediting responses to emerging healthcare challenges. For example, with the help of AI, Benevolent AI was able to pinpoint potential treatments for COVID-19 using the generic drug "baricitinib" within a few days [11]. The most important AI applications and examples are summarized in Table 2. In addition, AI platforms have reportedly enhanced the likelihood of success in the early phases of clinical testing, with some companies reporting an increase in phase 1 success rates from 40–65% to 80–90% [12]. Despite these successes, the biopharma sector faces significant challenges with AI adoption. These include a heavy dependence on large, high-quality data sets—which are often fragmented or inaccessible—and ethical concerns regarding intellectual property, transparency of algorithmic decisions and informed consent in AI-generated therapeutic pathways.

Like any emerging technology, the adoption of AI also faces certain challenges, including privacy issues, biases within algorithms and the absence of strict clinical validation. However, the use of AI in the pharmaceutical industry is certainly reshaping it for the better. This is evident in how it simplifies the processes for the professionals, from drug discovery to clinical trials and even in manufacturing, making effective medicines available faster [9]. This sets a new benchmark in the development of biopharmaceuticals and healthcare for people from every corner of the globe.

Innovation management strategies in AI development

Harnessing the transformative potential of AI in the healthcare and biopharma sectors requires proper innovation management. Organizations need to build an ecosystem that protects creativity and intellectual property while ensuring regulatory compliance to protect competitiveness and promote the sharing of knowledge [13]. Strategic management of intellectual property not only protects proprietary developments, but also facilitates collaborative scientific research and technology transfer from academia to industry and regulators [14].

In an analytical overview, Khoroshevsky, Efimenko & Efimenko outlined that collaboration significantly promotes the translation of AI research into clinically applicable practices. Partnerships between universities and healthcare providers, and industry clients have driven the integration of AI into drug discovery and patient care, thereby enhancing the impact of research on real-world challenges. Such collaboration is vital to effective technology transfer and rapid diffusion of innovations within the system [15]. However, interdisciplinary collaboration is often hindered by challenges such as the lack of shared technical vocabulary, conflicting organizational goals and data access limitations. For instance, healthcare providers may face constraints in sharing patient data with technology companies due to privacy regulations, hampering innovation. Addressing these barriers requires data-sharing agreements, ethical frameworks and joint governance structures.

There is a strong need for a robust governance structure to address the ethical challenges of AI innovation concerning bias, transparency and patient privacy. Machine learning, for instance, enables many institutions to collaboratively train AI models while keeping the raw data confidential, thus safeguarding privacy while driving innovation [16]. In this manner, the use of AI tools and data can be maximized while upholding ethical standards.

Another aspect of managing AI innovation entails interdisciplinary collaboration, including data scientists, clinicians and legal advisors. Agile frameworks and learning on the go are critical to organizational advancement in the face of the changing technological and regulatory landscapes [17]. Such flexibility is essential for keeping pace in a rapidly evolving environment. Real-world examples of successful implementation include AstraZeneca's AI innovation hub, which combines internal research and development with partnerships involving tech startups, hospitals and academic labs. This initiative has enabled faster identification of candidates for clinical trials and improved target validation.

Ultimately, the ethical governance frameworks defining responsible use of AI in healthcare and biopharma need to be formulated. An overview of ethical governance principles and supporting practices is provided in Table 3. These principles are further visualized in Figure 2. Addressing ethical risks and shifting regulatory landscapes while striving to maintain stakeholder trust requires these frameworks to govern the use of AI technology safely, dependably and fairly.

Figure 1. Application of AI across the biopharma value chain from target discovery to post-market surveillance.

Table 2. Summary of AI applications in biopharma

AI Application	Description	Real-World Example
Drug Discovery	Target identification, compound generation using AI	Insilico Medicine, Exscientia
Protein Structure Prediction	Predicts 3D protein structures for molecular design	DeepMind's AlphaFold
Clinical Trial Optimization	Optimizing recruitment and trial design with ML	IBM Watson Health, PathAI
Drug Repurposing	Identifying new indications for existing drugs	BenevolentAI (Baricitinib for COVID)

Innovation management implications

Adopting federated learning (a type of machine learning) in healthcare goes beyond technology implementation, but requires an organizational shift in AI innovation strategy. As Rieke et al. explained, "governance frameworks are critical for allocating access to data, ownership of models, and rights to publications of model results among the collaborating institutions [18]". Such frameworks help to solve issues of data privacy, traceability, and responsibility, which are especially vital for complex healthcare systems to support successful implementations of federated learning [19].

Another important aspect of federated learning is the lack of technical standardization. Institutions need to reach a consensus on dataset structure, model design, and security measures in order to collaborate across institutional boundaries [9]. In the absence of such standardization, a lack of interoperability can lead to data silos that undermine the additive value of machine learning, where data from multiple origins is aggregated for privacy-preserving analysis. This alignment guarantees the contribution and access to shared AI models by all participants [20].

The federated learning initiatives are successful when their incentive structures create value for all actors involved. By participating as contributors, organizational collaboration can be fostered with defined data control and contribution-based compensation mechanisms [18]. This collaborative model, alongside privacy-preserving frameworks, not only drives innovation in healthcare, but also forms a prototype for other sectors with data sharing predicaments, accelerating the adoption of responsible AI across industries.

Table 3. Ethical principles and governance practices in AI-driven healthcare

Ethical Principle	Description	Example Governance Practice
Transparency	Ensuring AI systems are explainable and understandable	Use of Explainable AI (XAI) tools in diagnostic systems
Accountability	Defining responsibility for AI-driven decisions and errors	Clear assignment of liability in AI clinical applications
Fairness & Non-Discrimination	Avoiding algorithmic bias and ensuring equitable access	Inclusion of diverse datasets during AI model training
Privacy & Data Protection	Safeguarding patient data during collection, sharing, and processing	Adoption of GDPR, HIPAA, and federated learning models
Human Oversight	Retaining human judgment in AI-assisted clinical decision-making	AI used as support tool, not autonomous decision-maker

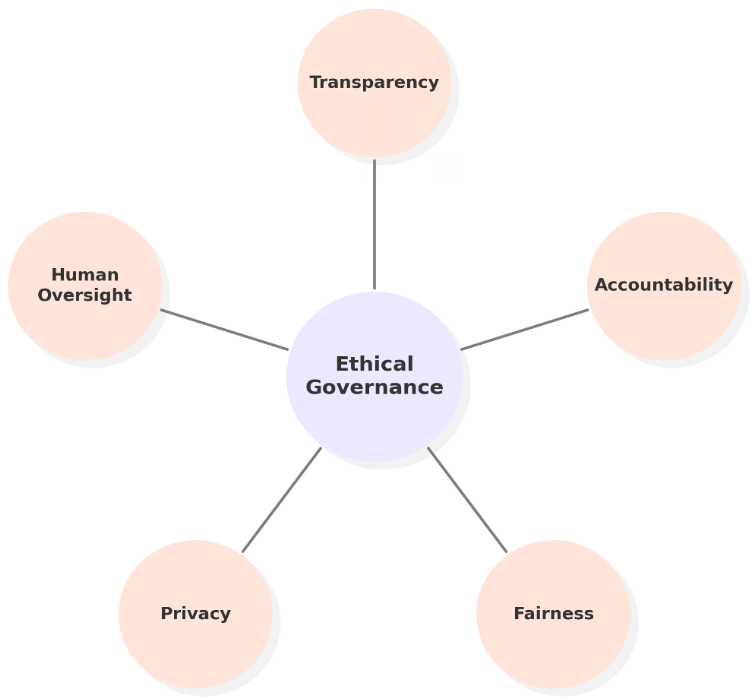

Figure 2. Key ethical principles supporting governance in AI-enabled healthcare and pharmaceutical innovation.

The evolution of personalized medicine through AI

Personalized (or precision) medicine represents a shift away from a "one size fits all" approach to healthcare by customizing care based on the personal genetics, environment and lifestyle of each patient [21, 22]. To accomplish optimal, acceptable treatment for each patient, genome-based approaches utilize advances in genomics, molecular biology and data science to determine what unique identifiers can be used to measure the difference in the risk of disease, disease condition and disease treatment. The ability to map the human genome and high-throughput sequencing technologies has forstered the ability for clinicians to identify the best medications and dosages for each patient. This ability is very valuable in disease areas such as oncology (cancer) and rare disease areas such as like Mendelian diseases [23].

It is evident that the combination of genomic, proteomic and other multi-omic health data improves diagnosis and prognosis, provides less variable therapy approaches (side effects and/or effects), and can improve the understanding of disease and potential disease-permitted treatments [22]. Clinicians have access to massive digital data sets from genetic tests, electronic health records and wearables that require computational tools to understand. These include improving the detection of diseases at earlier stages, more targeted interventions and improved management of chronic diseases. This data can significantly improve the overall safety and quality of patient care.

Despite its promise, personalized medicine faces challenges such as the high cost of genetic testing, the complexity of data interpretation and ethical concerns regarding privacy and bias. Ongoing research aims to expand diverse genetic databases and develop more accessible technologies that will help address health disparities and enhance the effectiveness of individualized therapies [24]. As personalized medicine continues to evolve, it is expected to revolutionize the prevention, diagnosis and treatment of diseases and provide more precise, effective and equitable healthcare solutions for diverse populations [25].

The research differs from the potential outlined here, and the differences can be alarming. Personalized medicine, though promising, struggles with issues such as the expense of genetic testing, the complexity of data and ethical issues related to privacy and bias. Our growing understanding and research in this area is focused on increasing genetic databases with diverse populations and costs. For example, recently swirl-based technology has been developed where you can swab the inside of your mouth or put some saliva in a bowl and send it to a lab, which then measure your saliva against a thousand molecular markers. Despite a long way ahead, personalized medicine is expected to change how diseases can be prevented, diagnosed and treated, and provide more targeted, effective and equitable healthcare solutions for different groups of patients [24, 25].

Challenges in AI innovation management

The integration of AI into healthcare and biopharma offers significant benefits, but also presents considerable challenges. Data quality and privacy remain critical, as AI models require accurate, secure and interoperable data to function effectively [26]. Fragmented data ecosystems and legacy infrastructure complicate seamless integration, while regulatory compliance is hindered by complex, evolving frameworks that require transparency and validation of AI algorithms [27]. Globally, efforts are underway to address these regulatory challenges. For instance, the European Union’s AI Act proposes a risk-based classification system for AI applications, while the U.S. Food and Drug Administration (FDA) has released draft guidelines for Good Machine Learning Practices (GMLP). However, these frameworks are still in flux and vary across regions, creating uncertainty for multinational companies.

Ethical challenges are paramount in AI innovation management. Bias in AI algorithms can exacerbate inequalities in healthcare. Therefore, it is essential to design systems that promote fairness and patient safety [28]. Autonomous AI agents raise questions of accountability and liability and necessitate clear governance frameworks to ensure responsible deployment [29]. The concerns on data privacy also persist. Machine learning has emerged as a promising approach that enables the collaborative traning of AI models without compromising sensitive patient information [30]. Technological advancements such as federated learning, blockchain for secure data exchange and explainable AI (XAI) are being explored as tools to address these issues. For instance, federated learning allows institutions to train models across decentralized data sources, improving privacy while enhancing model accuracy. Blockchain applications can further ensure data traceability, ownership rights and regulatory compliance.

Workforce adaptation is yet another barrier to personalized medicine. Personalized medicine is emerging in the health and pharmaceutical sectors, but there is a shortage of professionals who can understand not only the technical aspects of AI in health and drug development, but also the contexts of those developments and what they mean for patients and healthcare systems. Many healthcare professionals report insufficient training in AI literacy, while data scientists may lack the clinical context. Cross-functional trainings and interdisciplinary programmes are essential to bridge this gap. Organizations like Stanford and MIT have introduced specialized AI-in-healthcare curricula to address these needs.

We need to strengthen the gap between technical development and implementation in a clinical context. This requires a strong commitment to cross-functional collaboration, with data scientists, clinicians and regulatory experts, a cultural shift that encourages experimentation, and digital literacy across sectors that can impact it all [31, 32]. For example, organizations that involve clinical representatives in AI-related developments will have improved adoption rates of AI to support patient outcomes rather than impeding them [29].

From an operational perspective, the complexity of integrating AI tools into pre-existing healthcare structures is significant. Existing systems and silos of data complicate the swift implementation of AI solutions and justify the distraction when user adoption depends on agile methodologies and an atmosphere of continual learning. Organizations are increasingly investing in tailoring their own unique AI models and knowledge graph technologies to improve information retrieval and healthcare regulatory compliance. While AI innovations make it possible for every organization to access advanced AI solutions, they can be very expensive for small organizations [33]. Scalability remains a pressing concern, especially for low-resource facilities or small biotech firms. Solutions must be modular, cost-effective and supported by public-private partnerships to ensure equitable access to AI innovations.

Therefore, it can be said that the development demanding integration of an AI-enabled solution depends on the modernization of its infrastructures, while still aligning with regulation and, most importantly, considering operational continuity pressures. The key challenges associated with AI implementation and their practical mitigation strategies are presented in Table 4.

The integration of AI and AI-enabled solutions into healthcare routinely faces operational challenges, such as data privacy, ethical considerations, regulatory hurdles, workforce readiness and operational limitations. Addressing these operational challenges would typically require a meaningful incorporation of data governance principles, collaborative ventures for interdisciplinary participation in healthcare innovation implementation, management of innovation through agile, changing processes and clearly defined ethical guidelines to help us safely, effectively and equitably incorporate these AI technologies into our workplaces. Only through multi-stakeholder coordination and policy alignment can the full potential of AI be realized while safeguarding patient rights and system integrity.

If the industry matures, either collectively or through rational investment initiatives, and clearer regulatory pathways emerge, AI has the promising potential to revolutionize patient-centered outcomes and operational efficiencies in healthcare [34, 35].

Table 4. AI challenges and potential solutions

Challenge	Potential Solution/Tool
Data privacy	Federated learning, differential privacy methods
Algorithmic bias	Diverse datasets, fairness-aware ML models
Regulatory uncertainty	Adaptive regulatory frameworks, global harmonization
Workforce skill gaps	Interdisciplinary training and education programs
Integration into legacy systems	Modular AI tools, API-based integration

Future direction

New technologies, such as quantum computing, CRISPR gene editing, 3D bioprinting and organ systems chipping, are rapidly evolving and expanding the capabilities of AI in biopharma, leading to more rapid innovation in drug discovery, precision medicine and clinical trial design [36, 37]. The intersection of next-generation sequencing and multi-omics data provides rich and complex datasets that can be resolved using AI to identify new therapeutic targets and improve trial protocols, resulting in expected or improved outcomes with more personalized treatment plans [38]. These developments are transitioning us towards highly individualized therapies, particularly applicable to complex diseases such as cancer, where AI-driven molecular profiling will tailor therapy based on a patient's unique biology. However, these advances also come with potential risks and unintended consequences. The use of quantum computing for sensitive health data raises concerns about cybersecurity and data misuse. Similarly, the ethical implications of AI-assisted gene editing—particularly in the case of human embryos or germline interventions—also remain controversial and are not sufficiently regulated in many regions.

One development is the shift towards explainable AI models, which create transparency and trust related to AI-driven decisions and are particularly useful in areas such as target identification and drug repurposing

[39]. Network-based approaches are also becoming increasing popular as it is relatively easy to find new drug candidates after mapping complex biological interactions. The use of digital twins and predictive modelling for clinical trial design is also reducing costs and shortening timelines while improving the interpretive consistency [40]. These innovations are not only transforming research and development processes, but also laying the foundation for a more efficient and patient-centred drug development ecosystem. However, scalability and accessibility remain major concerns, particularly for lower-income regions. Many AI tools are developed in high-resource environments with assumptions that may not apply to the whole world. Ensuring equitable access requires international coordination, capacity building and adaptation of tools for varied clinical and regulatory contexts.

Moving forward, the future of AI in healthcare and biopharma will need to focus on some key areas: developing standards for AI use across the industry, aligning with current technologies, global coordination to share learnings and resources, and a commitment to patients as the focus of all AI development efforts [41]. Examples include the World Health Organization's (WHO) Global Strategy on Digital Health and international partnerships such as the Global Alliance for Genomics and Health (GA4GH), which aim to standardize frameworks for the ethical and interoperable use of biomedical data. As this sector evolves, all of these efforts will be important to maximize the opportunities for AI, while ensuring safety and transparency and promoting equitable access to new therapies [42].

Conclusion

Innovation management is essential for driving change in healthcare and biopharma, as digital technologies are changing the landscape of drug discovery, enabling personalized medicine, leading to new diagnostic innovations and improving clinical trial processes. These advances enable organizations to rapidly develop and deploy therapies, which are incredibly impactful for diseases such as cancer and other chronic diseases. Organizations need to adopt clear and robust innovation management practices, including adequate protection of their intellectual property, compliance with standards and regulations and ensuring ethical governance standards to ensure transparency and fairness in the use of data. Partnerships and collaboration are essential for organizations to effectively share knowledge and transfer technologies with industry, academia and regulators.

To move forward successfully, stakeholders should adopt a set of actionable strategies:

- Implement a structured innovation framework that combines technical agility with regulatory foresight.
- Invest in workforce training to bridge the gap between technologists and healthcare professionals in AI.
- Utilize ethical AI principles—such as transparency, accountability and inclusivity—to guide development and deployment.
- Establish cross-border governance collaborations to promote data interoperability and equitable access to AI-driven solutions.

By addressing planning and ethical standards to overcome persistant challenges such as data quality, regulatory difficulties and algorithmic bias, we will unlock the potential of digital innovations for the benefit of patient care and global health. Ultimately, innovation management must not only promote technological progress, but also ensure that such progress is safe, inclusive and centered on the human well-being.

Funding statement

This research received no external funding.

Ethical compliance

Not applicable.

Data access statement

All data discussed in this review article are derived from publicly available sources as cited in the references and supplementary materials.

Conflict of interest

The authors declare that they are not affiliated with or involved in any organization or entity that has a financial interest in the subject matter or materials discussed in this manuscript.

Authors' contributions

Sabeen Khaliq conducted the literature review, collected references, drafted the manuscript and implemented revisions. Professor Konstantin Koshechkin supervised the research process and critically reviewed the initial draft. All authors contributed to the final version of the manuscript and approved it for the publication.

References

[1] Ibraheem Ali, Koshechkin K. Advancing drug

discovery: the role of AI and machine learning in accelerating therapeutic. *Journal of Sciences*. 2025; 4(2 (83)), 587-597.

[2] Arlen Meyers. Bioentrepreneurship: opportunities and challenges. In: Satish Nambisan (ed) *Embracing Entrepreneurship Across Disciplines*. 2015; 73-85. doi: 10.4337/9781782549963.00013.

[3] Bonnie Clipper, Tami H. Wyatt, Michael Ackerman, Tim Raderstorf. Emerging Trends in Healthcare Innovation. In: Bernadette Mazurek Melnyk, Tim Raderstorf (eds) *Evidence-Based Leadership, Innovation and Entrepreneurship in Nursing and Healthcare: A Practical Guide to Success*. 2019; doi: 10.1891/9780826160720.0018.

[4] Attila A. Seyhan, Claudio Carini. Are innovation and new technologies in precision medicine paving a new era in patient-centric care? *Journal of translational medicine*. 2019; 17(1). doi: 10.1186/s12967-019-1864-9.

[5] Whende M. Carroll. Emerging technologies and healthcare innovation. In: *Emerging technologies for nurses–Implications for practice*. 2021; 13-16.

[6] Raghav Awasthi, Sai Prasad Ramachandran, Shreya Mishra, Dwarikanath Mahapatra, Hajra Arshad, Aarit Atreja, et al. Artificial Intelligence in Healthcare: 2024 Year in Review. medRxiv. 2025-02. doi: 10.1101/2025.02.26.25322978.

[7] Chen Fu, Qiuchen Chen. The future of pharmaceuticals: Artificial intelligence in drug discovery and development. *Journal of Pharmaceutical Analysis*. 2025; 101248. doi: 10.1016/j.jpha.2025.101248.

[8] Suriyaamporn P, Pamornpathomkul B, Patrojanasophon P, Ngawhirunpat T, Rojanarata T, Opanasopit P. The artificial intelligence-powered new era in pharmaceutical research and development: a review. *AAPS PharmSciTech*. 2024; 25(6), 188. doi: 10.1208/s12249-024-02901-y.

[9] Fan Zhang, Daniel Kreuter, Yichen Chen, Sören Dittmer, Samuel Tull, et al. Recent methodological advances in federated learning for healthcare. *Patterns*. 2024; 5(6). doi: 10.1016/j.patter.2024.101006.

[10] Rushikesh Dhudum, Ankit Ganeshpurkar, Atmaram Pawar. Revolutionizing drug discovery: A comprehensive review of AI applications. *Drugs and Drug Candidates*. 2024; 3(1), 148-171. doi: 10.3390/ddc3010009.

[11] Yadi Zhou, Fei Wang, Jian Tang, Ruth Nussinov, Feixiong Cheng. Artificial intelligence in COVID-19 drug repurposing. *The Lancet Digital Health*. 2020; 2(12): e667-e676. doi: 10.1016/S2589-7500(20)30192-8.

[12] Ai Amin, Iffat Quaes Chowdhury, Rodshi Abyaz, et al. Artificial Intelligence in Pharmacy: Innovations, Applications, and Future Emerging Challenges. *International Journal of Scientific Research in Engineering and Management*. 2024; 08(12): 1-18. doi: 10.55041/IJSREM40335.

[13] Stefan Harrer, Jeffrey Menard, Michael Rivers, Darren V.S. Green, Joel Karpiak, et. al. Artificial intelligence drives the digital transformation of pharma. In: *Artificial Intelligence in clinical practice*. 2024: 345-372. doi: 10.1016/B978-0-443-15688-5.00049-8.

[14] Naomi Haefner, Joakim Wincent, Vinit Parida, Oliver Gassmann. Artificial intelligence and innovation management: A review, framework, and research agenda. *Technological Forecasting and Social Change*. 2021; 162: 120392. doi: 10.1016/j.techfore.2020.120392.

[15] Khoroshevsky, V. F., Efimenko, V. F., Efimenko, I. V. Artificial intelligence, biotechnology and medicine: Reality, myths and trends. In: Kuznetsov, S.O., Panov, A.I., Yakovlev, K.S. (eds) Artificial Intelligence. RCAI 2020. *Lecture Notes in Computer Science*. 2020; 12412. Springer, Cham. doi: 10.1007/978-3-030-59535-7_31

[16] Hassan, M., Borycki, E. M., Kushniruk, A. W. Artificial intelligence governance framework for healthcare. *Healthcare Management Forum*. 2024; 38(2), 125-130. doi: 10.1177/08404704241291226.

[17] Singh, B. Artificial Intelligence (AI) in the Digital Healthcare and Medical Industry: Projecting Vision for Governance and Regulations. In: B. Soufiene, C. Chakraborty (Eds.) *Responsible AI for Digital Health and Medical Analytics*. 2025; pp. 161-188. doi: 10.4018/979-8-3693-6294-5.ch007.

[18] Nicola Rieke, Jonny Hancox, Wenqi Li, Fausto Milletarì, Holger R. Roth et, al. The future of digital health with federated learning. NPJ digital medicine. 2020; 3(1). doi: 10.1038/s41746-020-00323-1.

[19] Paul-Philipp Jacobs, Constantin Ehrengut, Andreas Michael Bucher, Tobias Penzkofer, et al. Challenges in Implementing the Local Node Infrastructure for a National Federated Machine Learning Network in Radiology. *Healthcare*. 2023; 11(17): 2377. doi: 10.3390/healthcare11172377.

[20] Adegoke, K.; Adegoke, A.; Dawodu, D.; Bayowa, A.; Adekoya, A. Interoperability in Digital Healthcare: Enhancing Consumer Health and Transforming Care Systems. Preprints. 2025; 2025021774. doi: 10.20944/preprints202502.1774.v1.

[21] Minnie Jacob, Andreas L. Lopata, Majed Dasouki, Anas M. Abdel Rahman. Metabolomics toward personalized medicine. *Mass Spectrometry Reviews*. 2019; 38(3): 221-238. doi: 10.1002/mas.21548.

[22] Sunil Mathur, Joseph Sutton. Personalized medicine could transform healthcare. *Biomedical Reports*. 2017; 7(1), 3-5. doi: 10.3892/br.2017.922.

[23] Morganti, S., Tarantino, P., Ferraro, E., D'Amico, P., Viale, G., Trapani, D., Curigliano, G. Role of next-generation sequencing technologies in personalized medicine. In: Pravettoni, G., Triberti, S. (eds) *P5*

eHealth: An Agenda for the Health Technologies of the Future. Springer, Cham. doi: 10.1007/978-3-030-27994-3_8.

[24] Dean Ho, Stephen R. Quake, Edward R. B. McCabe, Wee Joo Chng, et, al. Enabling technologies for personalized medicine. *Trends in Biotechnology*. 2020; 38(5), 497-518. doi: 10.1016/j.tibtech.2019.12.021.

[25] Kayser, C., Dutra, L. A., dos Reis-Neto, E. T., Castro, C. H. D. M., Fritzler, M. J., Andrade, L. E. C. The role of autoantibody testing in modern personalized medicine. *Clinical Reviews in Allergy & Immunology*. 2022; 63(2), 251-288. doi: 10.1007/s12016-021-08918-6.

[26] Holzinger, A., Keiblinger, K., Holub, P., Zatloukal, K., Müller, H. AI for life: Trends in artificial intelligence for biotechnology. *New Biotechnology*. 2023; 74, 16-24. doi: 10.1016/j.nbt.2023.02.001.

[27] Khan, S., Majdalawieh, M., Kharadi, D., Verma, T., Farhin, T., Kumar, A. From Digital Disruption to AI Revolution: The Evolution of Healthcare Transformation. *Artificial Intelligence in Medicine and Healthcare*. 2025; 31.

[28] Bohr, A., Memarzadeh, K. Current healthcare, big data, and machine learning. In: *Artificial Intelligence in Healthcare*. 2020; 1-24. doi: 10.1016/B978-0-12-818438-7.00001-0.

[29] Koshechkin, K. A., Lebedev, G. S., Fartushnyi, E. N., Orlov, Y. L. Holistic approach for artificial intelligence implementation in pharmaceutical products lifecycle: a meta-analysis. *Applied Sciences*. 2022; 12(16): 8373. doi: 10.3390/app12168373.

[30] Apell, P., Eriksson, H. Artificial intelligence (AI) healthcare technology innovations: the current state and challenges from a life science industry perspective. *Technology Analysis & Strategic Management*. 2023; 35(2), 179-193. doi: 10.1080/09537325.2021.1971188 .

[31] Kemppainen, L., Pikkarainen, M., Hurmelinna-Laukkanen, P., Reponen, J. Connected health innovation: data access challenges in the interface of AI companies and hospitals. *Technology Innovation Management Review*. 2019; 9(12): 43-55. doi: 10.22215/timreview/1291.

[32] Disha Gupta. How AI is Reshaping Pharma: Use Cases and Challenges. 2025. Available from: https://whatfix.com/blog/ai-in-pharma/. [Accessed 9th July 2025].

[33] Bio-IT World. Trendspotting: Predictions for Bio-IT World in 2025. Available from: https://www.bio-itworld.com/news/2025/01/07/trendspotting-predictions-for-bio-it-world-in-2025. [Accessed 9th July 2025].

[34] Broekhuizen, T., Dekker, H., de Faria, P., Firk, S., Nguyen, D. K., Sofka, W. AI for managing open innovation: Opportunities, challenges, and a research agenda. *Journal of Business Research*. 2023; 167, 114196. doi: 10.1016/j.jbusres.2023.114196.

[35] Koshechkin, K., Lebedev, G., Radzievsky, G., Seepold, R., Martinez, N. M. Blockchain technology projects to provide telemedical services: Systematic review. *Journal of Medical Internet Research*. 2021; 23(8), e17475. doi: 10.2196/17475.

[36] Oborotov, G. A., Koshechkin, K. A., Orlov, Y. L. Application of Artificial Intelligence or machine learning in risk-sharing agreements for pharmacotherapy risk management. *Journal of Integrative Bioinformatics*. 2023; 20(3), 20230014. doi: 10.1515/jib-2023-0014.

[37] Lea-Smith, D. J., Hassard, F., Coulon, F., Partridge, N., Horsfall, L., Parker, K. D., Krasnogor, N. Engineering biology applications for environmental solutions: potential and challenges. *Nature Communications*. 2025; 16(1), 3538. doi: 10.1038/s41467-025-58492-0.

[38] Mohanan, P. V. Artificial Intelligence and Biological Sciences. Boca Raton: Taylor & Francis Group; 2025. doi: 10.1201/9781003492726.

[39] Chandak, T., Jayashree, J., Vijayashree, J. Trends and Advancements of AI and XAI in Drug Discovery. In: *Explainable AI (XAI) for Sustainable Development*. 2024; pp. 233-255. Chapman and Hall/CRC.

[40] Wray, J., Whitmore, A. Network-driven drug discovery. In: *Artificial Intelligence in Drug Design*. 2021; pp. 177-190. New York, NY: Springer US.

[41] Aritra, S., Indu, S. Harnessing the Power of Artificial Intelligence in Pharmaceuticals: Current Trends and Future Prospects. *Intelligent Pharmacy*. 2025; 3(3): 181-192. doi: 10.1016/j.ipha.2024.12.001.

[42] Baumgartner, R., Arora, P., Bath, C., Burljaev, D., Ciereszko, K., Custers, B., Williams, R. Fair and equitable AI in biomedical research and healthcare: Social science perspectives. *Artificial Intelligence in Medicine*. 2023; 144: 102658. doi: 10.1016/j.artmed.2023.102658.