RES MILITARIS
REVUE EUROPEENNE D ETUDES EUROPEAN JOURNAL OF MILITARY STUDIES
Social Science Journal

# Review Article on Application of AI in Pharmaceutical Research and Healthcare

**Ashish K. Parashar*, Lalit K. Tyagi[1], Vandana Arora[2], Neelam Jain[3], Neeraj Jain[4], Sayantan Dutta[5]**

*[1,2]Lloyd Institute of Management and Technology, Plot No.-11, Knowledge Park-II, Greater Noida, Uttar Pradesh, India-201306

[3]Faculty of Pharmacy, Oriental University, Indore-453555, M.P., India.

[4]Teerthankar Mahaveer College of Pharmacy, TMU, Moradabad- 244001, U.P., India.

[5]Faculty of Pharmaceutical sciences Rama University, Mandhana, Kanpur-209217, U.P., India.

***Corresponding Author**

Dr. Ashish Kumar Parashar

Lloyd Institute of Management and Technology, Plot No.-11, Knowledge Park-II, Greater Noida, Uttar Pradesh, India-201306

Email: ashish.parashar1@gmail.com

## ABSTRACT

Through a comprehensive analysis of the current state of AI in pharmaceutical research and healthcare, this review aims to provide valuable insights into the opportunities, challenges, and future prospects of AI adoption in this critical industry. Application of artificial intelligence in pharmaceutical research and healthcare has the potential to revolutionize the industry and improve patient outcomes. This review article provides an in-depth analysis of the current state of AI in pharmaceutical research and its impact on drug discovery, development, and clinical trials. Additionally, it explores the use of AI technologies in healthcare settings, including diagnostic imaging, personalized medicine, and patient care. By examining the latest advancements and challenges in this field, this review aims to provide a comprehensive overview of the opportunities and limitations of AI in pharmaceutical research and healthcare, ultimately shedding light on the future direction of this rapidly evolving field.

**Keywords:** Artificial intelligence, drug discovery, development, clinical trials, personalized medicine, patient care.

## INTRODUCTION

Artificial intelligence has rapidly transformed the pharmaceutical and healthcare industries, revolutionizing the way research is conducted and patient care is delivered. In pharmaceutical research, AI is being utilized to analyze vast amounts of data to identify potential drug candidates, predict their efficacy, and even design new molecules with specific properties. This has significantly accelerated the drug discovery and development process, leading to the potential for faster and more cost-effective production of new medications (Kirkpatrick, 2022) (Drug Discovery and Development Archives, 2023).

In healthcare, AI is being deployed in various applications, ranging from personalized treatment recommendations and medical imaging analysis to predictive analytics for patient outcomes and population health management. Machine learning algorithms are enabling healthcare providers to tailor treatment plans to individual patients, leading to improved outcomes and (Schork,

2012)(Curth, 2023) reduced healthcare costs. Additionally, AI is playing a crucial role in identifying patterns and trends in large patient datasets, ultimately contributing to early disease detection and prevention strategies.

As AI continues to evolve, it is poised to further enhance the efficiency and effectiveness of pharmaceutical research and healthcare delivery, ultimately leading to improved patient outcomes and a more sustainable healthcare system. The integration of AI in pharmaceutical research and healthcare has also shown promise in streamlining clinical trials. By leveraging AI algorithms, researchers can identify suitable patient populations for clinical trials more effectively, leading to faster recruitment and more diverse participant groups. This not only expedites the trial process but also improves the generalizability of the results, ultimately benefiting the broader patient population. (Increasing Diversity In Clinical Trials: The Critical Role Of Community Partnerships & Collaborations, 2023)

Furthermore, in the realm of healthcare delivery, AI-powered chatbots and virtual assistants are offering personalized support and guidance to patients, empowering them to manage their health proactively and conveniently. These tools can provide valuable information, reminders for medication adherence, and even offer initial triage for non-emergency medical queries, thus easing the burden on healthcare facilities and enabling timely access to care for patients (HealthCare App Development Company - MobileCoderz, 2020).

Looking ahead, the continuous advancements in AI technology bring the potential for even more sophisticated applications in pharmaceutical research and healthcare, ranging from precision medicine to proactive intervention strategies. As AI becomes increasingly integrated into these sectors, it is crucial for industry stakeholders to ensure ethical, transparent, and responsible deployment, prioritizing patient privacy and safety while harnessing the full potential of this transformative technology.Introduction (W, 2024)(Cooper, 2020).

Artificial intelligence has become a game-changer in the pharmaceutical and healthcare sectors, revolutionizing how research is conducted and patient care is delivered (Tekade, 2021)(Chavda, 2023). Its applications in drug discovery, personalized treatment recommendations, medical imaging analysis, and clinical trials have significantly transformed the landscape of pharmaceutical research and healthcare delivery. As AI continues to evolve, it holds the promise of further enhancing the efficiency and effectiveness of these sectors, ultimately leading to improved patient outcomes and a more sustainable healthcare system(W, 2024)(M, 2023).

The integration of AI in pharmaceutical research and healthcare has also shown promise in streamlining clinical trials, offering personalized support to patients through AI-powered chatbots and virtual assistants, and paving the way for more sophisticated applications such as precision medicine and proactive intervention strategies.(Nicholas, 2019) As these advancements continue, it is essential for industry stakeholders to ensure the ethical, transparent, and responsible deployment of AI, prioritizing patient privacy and safety while harnessing the full potential of this transformative technology. With the continued advancements in AI technology, there is a growing focus on the development of precision medicine.(Arasteh et al., 2024) By leveraging AI algorithms and analyzing vast amounts of clinical and genetic data, researchers

and healthcare providers can tailor treatment plans and interventions to individual patients based on their unique genetic makeup, lifestyle, and environmental factors. (Colijn et al., 2017) This approach has the potential to significantly improve patient outcomes by ensuring that treatments are personalized and targeted to address specific characteristics and needs of each patient. (Evers et al., 2012)

Moreover, proactive intervention strategies are also emerging as a promising application of AI in healthcare. By analyzing data from various sources including patient health records, wearable devices, and environmental sensors, AI can help identify early indicators of health issues and potential risks. This allows healthcare providers to intervene proactively, potentially preventing the development of serious conditions and improving overall population health.

As AI becomes increasingly integrated into pharmaceutical research and healthcare delivery, it is essential for industry stakeholders to collaborate closely with regulatory bodies to establish clear guidelines for the ethical and responsible use of AI technologies.(Everson et al., 2024) Ensuring patient privacy, data security, and transparent decision-making processes will be essential as AI continues to play a pivotal role in shaping the future of pharmaceutical research and healthcare.(S, 2023)

While the integration of AI in pharmaceutical research and healthcare has undoubtedly shown promise in various applications, it is essential to consider the potential drawbacks and challenges associated with the widespread adoption of AI technology in these sectors. (H, 2019)

One of the primary concerns is the overreliance on AI algorithms for decision-making in healthcare. While AI can analyze vast amounts of data and provide insights, there is the risk of dehumanizing the patient care experience. Relying solely on AI-generated recommendations for treatment plans and interventions may overlook the human aspects of healthcare, such as empathy, emotional support, and the holistic understanding of patient needs. (Daly, 2018)

Additionally, there are concerns about the transparency and interpretability of AI algorithms in healthcare and pharmaceutical research. The complexity of AI models and the lack of clear explanations for their outputs raise questions about accountability and trust. Patients and healthcare providers may find it challenging to understand and trust the recommendations made by AI systems, especially when the decision-making process is not transparent. (London, 2022)(Sivaraman et al., 2023)(Golden et al., 2024)

Furthermore, the ethical implications of AI deployment in healthcare and pharmaceutical research need careful consideration. The use of AI for personalized treatment recommendations and early disease detection raises questions about data privacy, consent, and the potential for bias in algorithmic decision-making. There is a risk of exacerbating existing healthcare disparities if AI algorithms are not carefully designed and implemented to account for diverse patient populations and socioeconomic factors.(Nordling, 2019)(Chen et al., 2020)

As AI continues to advance and be more deeply integrated into these sectors, it is crucial for industry stakeholders to address these challenges and work towards mitigating the potential risks. Balancing the benefits of AI with the preservation of human-centric care, ensuring transparency and interpretability of AI systems, and upholding ethical standards in the use of patient data will

be essential for the responsible and sustainable integration of AI in pharmaceutical research and healthcare. (Pardalos, 2023) The integration of AI in pharmaceutical research and healthcare has indeed led to significant advancements, particularly in the development of precision medicine. By harnessing the power of AI algorithms to analyze extensive clinical and genetic data, researchers and healthcare providers can now tailor treatment plans and interventions to each patient's unique genetic makeup, lifestyle, and environmental factors. This personalized approach holds great promise in improving patient outcomes by ensuring that treatments are precisely targeted to address the individual characteristics and needs of each patient. (Qattan et al., 2012)

Furthermore, proactive intervention strategies have emerged as a particularly promising application of AI in healthcare. Through the analysis of data from various sources, including patient health records, wearable devices, and environmental sensors, AI can effectively identify early indicators of health issues and potential risks. This capability allows healthcare providers to intervene proactively, potentially preventing the development of serious conditions and ultimately improving overall population health (Nakayama et al., 2022).

However, as AI becomes increasingly integrated into pharmaceutical research and healthcare delivery, industry stakeholders must recognize the critical importance of collaborating closely with regulatory bodies to establish clear guidelines for the ethical and responsible use of AI technologies. Ensuring patient privacy, data security, and transparent decision-making processes will be essential as AI continues to play a pivotal role in shaping the future of pharmaceutical research and healthcare. (S, 2024)

**APPLICATION OF AI IN DRUG DISCOVERY**

In addition to its impact on precision medicine and proactive intervention strategies, AI has also shown significant potential in revolutionizing the drug discovery process. Traditional drug discovery and development processes are time-consuming and expensive, with a high rate of failure (Kirkpatrick, 2022) (Qureshi et al., 2023). AI technologies offer a promising solution to these challenges by expediting the identification of novel drug candidates, predicting their efficacy and safety profiles, and optimizing clinical trial designs (Sadybekov & Katritch, 2023).

AI algorithms can analyze vast databases of chemical compounds, protein structures, and genetic information to identify potential drug targets and lead compounds with greater speed and accuracy than traditional methods. This not only accelerates the initial stages of drug discovery but also facilitates the identification of drug candidates for complex diseases with diverse underlying biological mechanisms. (Hopper, 2023)(Sadybekov & Katritch, 2023)

Moreover, AI enables the prediction of drug-target interactions and the assessment of potential side effects, thereby enhancing the selection of promising lead compounds for further development. By leveraging machine learning algorithms, researchers can better predict the pharmacokinetic and pharmacodynamic properties of candidate drugs, leading to more informed decisions in the drug development process. (Réda et al., 2020)

Furthermore, AI contributes to the optimization of clinical trial designs by analyzing real-world patient data, identifying relevant biomarkers, and stratifying patient populations. This approach

enhances the efficiency and cost-effectiveness of clinical trials, ultimately expediting the delivery of new therapies to patients (Renfro et al., 2016).

The application of AI in drug discovery holds the potential to transform the pharmaceutical industry by accelerating the development of innovative and targeted therapies, reducing the overall cost and risk of drug development, and ultimately improving patient access to life-saving medications (Mock et al., 2023).

In the era of AI-driven drug discovery, it is imperative for industry stakeholders and regulatory bodies to collaborate in establishing robust guidelines for the ethical and responsible use of AI technologies in pharmaceutical research. Safeguarding patient privacy, ensuring the transparency of AI-driven decision-making, and mitigating the potential biases in algorithmic predictions will be crucial for the successful integration of AI in drug discovery while upholding ethical standards. (Panch et al., 2019)

## APPLICATION OF AI IN FORMULATION DEVELOPMENT

In addition to its significant impact on precision medicine, proactive intervention strategies, and drug discovery, AI has also demonstrated great potential in the formulation development process within the pharmaceutical industry. (Rosenberger, 2023)

AI technologies have streamlined the formulation development process by enabling rapid analysis and optimization of drug formulations. Through the utilization of machine learning algorithms, researchers can efficiently analyze the interactions between various excipients, active pharmaceutical ingredients, and the physicochemical properties of the drug substance. This capability enhances the understanding of formulation components and their impact on drug stability, bioavailability, and delivery mechanisms. (Mishra et al., 2023)

Furthermore, AI plays a crucial role in predicting the behavior and performance of formulations under different manufacturing and environmental conditions. By leveraging predictive modeling and simulations, researchers can anticipate potential formulation challenges and optimize the manufacturing processes to ensure the consistency and quality of the final product. (Hwang & Noack, 2011)

Moreover, AI-driven tools facilitate the identification of novel formulation strategies for complex drug compounds, enabling the development of innovative dosage forms that enhance patient compliance and therapeutic outcomes. The ability to generate and analyze vast amounts of formulation data expedites the identification of optimal drug delivery systems tailored to specific patient needs.(Lane et al., 2012)(Narang et al., 2007)

The integration of AI in formulation development not only accelerates the development of safe and effective drug formulations but also contributes to the overall efficiency and cost-effectiveness of pharmaceutical research and development.

As AI continues to redefine formulation development in the pharmaceutical industry, collaboration between industry stakeholders and regulatory bodies is imperative to establish clear guidelines for the ethical and responsible use of AI technologies. Ensuring the transparency and interpretability of AI-driven formulation development processes, safeguarding patient safety, and

mitigating potential biases in algorithmic decision-making will be essential for the successful and ethical integration of AI in this crucial aspect of pharmaceutical research and development.(Savage, 2021)(Mehta et al., 2019)

**APPLICATION OF AI IN CLINICAL TRIALS**

AI has become an invaluable tool in the optimization and execution of clinical trials, revolutionizing the process and ultimately improving patient outcomes. By leveraging AI technologies, pharmaceutical companies and research organizations can streamline various aspects of clinical trials, from patient recruitment to data analysis, resulting in more efficient and effective trial processes.(Silcox et al., 2024)

One of the key applications of AI in clinical trials is in the identification of suitable patient populations and the personalization of treatment strategies. AI algorithms can analyze diverse sets of patient data to identify specific biomarkers, genetic profiles, and other relevant characteristics that can help in the selection of suitable candidates for clinical trials. This personalized approach ensures that treatments are targeted to address individual patient needs, ultimately leading to improved outcomes and a higher likelihood of treatment success. (Fountzilas et al., 2022)(Singer, 2005)

Furthermore, AI contributes to the optimization of clinical trial designs by monitoring and analyzing real-world patient data, identifying relevant biomarkers, and stratifying patient populations. By doing so, AI can improve the efficiency and cost-effectiveness of clinical trials, ultimately expediting the delivery of new therapies to patients.

The integration of AI in clinical trials also facilitates the identification of early indicators of health issues and potential risks, allowing for proactive intervention strategies. By analyzing various data sources, including patient health records, wearable devices, and environmental sensors, AI can effectively identify early indicators of health issues, enabling healthcare providers to intervene proactively and potentially prevent the development of serious conditions. (Chen et al., 2023)(Wang et al., 2024)

Moreover, AI technologies contribute to the analysis and interpretation of the vast amount of data generated during clinical trials, helping researchers to identify patterns, predict outcomes, and optimize trial processes. This not only expedites the clinical trial timelines but also ensures the accuracy and reliability of the data collected, leading to more informed decision-making and ultimately contributing to the development of safe and effective treatments. (Krishnankutty et al., 2012).

As the pharmaceutical industry increasingly integrates AI into clinical trials, collaboration between industry stakeholders and regulatory bodies is essential to establish clear guidelines for the ethical and responsible use of AI technologies. This includes ensuring patient privacy, data security, and transparent decision-making processes. Additionally, it is crucial to mitigate potential biases in algorithmic predictions to uphold ethical standards and ensure the integrity of clinical trial processes. (Gianfrancesco et al., 2018).

The application of AI in clinical trials holds significant promise in improving the efficiency, effectiveness, and ethical standards of pharmaceutical research and healthcare delivery. As AI

continues to play a pivotal role in shaping the future of clinical trials, it is imperative to prioritize collaboration and the establishment of robust ethical guidelines to ensure the responsible and beneficial integration of AI technologies in this critical aspect of healthcare and drug development.

**APPLICATION OF AI IN PATIENT CARE**

In addition to its extensive impact on pharmaceutical research and development, AI offers significant applications in patient care, transforming the delivery of healthcare services and enhancing patient outcomes. The integration of AI in patient care encompasses a wide range of capabilities aimed at improving diagnostic accuracy, treatment personalization, and overall healthcare delivery. (Dave & Patel, 2023)(Khalifa et al., 2024)

One of the key applications of AI in patient care is in diagnostic support and medical imaging analysis. AI algorithms can analyze medical imaging data such as X-rays, MRIs, and CT scans to assist healthcare professionals in detecting and diagnosing medical conditions with greater accuracy and efficiency. By leveraging machine learning and pattern recognition, AI can help in early detection of diseases, consequently enabling timely intervention and improved patient outcomes. (Hosny et al., 2018) (Pesapane et al., 2018)

Furthermore, AI contributes to the personalization of treatment plans and interventions by analyzing vast amounts of patient data to identify optimal treatment strategies tailored to individual patient characteristics. By integrating patient-specific data, including genetic information, medical history, and environmental factors, AI can assist healthcare providers in developing personalized treatment plans that align with each patient's unique needs and characteristics.

Another crucial application of AI in patient care is in predictive analytics and risk stratification. AI technologies can analyze patient data to identify individuals at a higher risk of developing certain medical conditions or experiencing adverse health events. This enables healthcare providers to proactively intervene, provide preventive care, and manage chronic conditions more effectively, ultimately leading to better health outcomes and reduced healthcare costs. (Li et al., 2010)(Diehr et al., 2007).

Moreover, AI-driven tools such as virtual health assistants and chatbots can enhance patient engagement, provide real-time information, and support patients in managing their health and treatment regimens. These tools offer continuous support and guidance to patients, improving medication adherence, facilitating remote monitoring, and enabling timely communication with healthcare providers.

The integration of AI in patient care not only enhances clinical decision-making and treatment outcomes but also contributes to the overall efficiency and quality of healthcare delivery. As AI continues to reshape patient care, collaboration between healthcare providers, technology developers, and regulatory bodies is essential to establish clear guidelines for the ethical and responsible use of AI technologies in patient care. This includes ensuring patient privacy, data security, and the transparency of AI-driven decision-making processes. Additionally, it is crucial

to mitigate potential biases in algorithmic predictions to uphold ethical standards and ensure the integrity of patient care processes. (Mittermaier et al., 2023)(Gianfrancesco et al., 2018)

The application of AI in patient care holds immense promise in improving healthcare delivery, patient outcomes, and overall healthcare efficiency. As AI technologies continue to play an increasingly significant role in shaping the future of healthcare, the establishment of robust ethical guidelines and collaborative efforts will be pivotal in ensuring the responsible and beneficial integration of AI in patient care. (Zhang & Zhang, 2023)

## FUTURE SCOPE AND CHALLENGES

The integration of AI in clinical trials and patient care presents a promising future with significant advancements in healthcare delivery and pharmaceutical research. As AI technologies continue to evolve and integrate into these critical aspects of healthcare, several future scopes and challenges can be anticipated.

### Future Scope

#### Enhanced Personalization and Targeted Therapies

The future of AI in clinical trials is expected to further advance the personalization of treatment strategies. With the integration of genomics, proteomics, and other omics data, AI can lead to the development of highly targeted therapies tailored to individual patient characteristics. This level of precision medicine holds the potential to revolutionize the approach to treating complex diseases and improving patient outcomes.

#### Predictive and Preventive Healthcare

AI is poised to play a crucial role in predictive and preventive healthcare initiatives. By analyzing comprehensive patient data, including genetic predispositions, lifestyle factors, and environmental influences, AI can enable the early identification of health risks and empower healthcare providers to intervene proactively. This proactive approach has the potential to reduce the burden of chronic diseases and improve overall population health.

#### Integration of Multi-Omics Data

The future integration of multi-omics data, such as genomics, transcriptomics, proteomics, and metabolomics, presents an opportunity for AI to unravel complex disease mechanisms and identify novel therapeutic targets. This comprehensive analysis of biological pathways and molecular interactions can significantly accelerate the discovery of new treatments and the development of precision medicine approaches.

### Challenges

#### Data Privacy and Security

As the reliance on AI for clinical trials and patient care increases, ensuring the privacy and security of sensitive patient data remains a paramount challenge. Striking a balance between leveraging patient data for AI-driven insights while safeguarding privacy and complying with data protection regulations will require ongoing efforts and robust data governance frameworks.

#### Algorithm Bias and Interpretability

Addressing algorithmic bias in AI models used for clinical trials and patient care poses a critical challenge. Ensuring the fairness and transparency of AI-generated insights, particularly in

decision-making processes, is essential to mitigate the risk of bias affecting patient outcomes and trial results. Additionally, enhancing the interpretability of AI-driven predictions and recommendations will be crucial for building trust among healthcare professionals and patients.

**Regulatory and Ethical Frameworks**

The evolving landscape of AI technologies in healthcare necessitates the establishment of clear and adaptable regulatory frameworks. Regulators and policymakers will need to collaborate with industry stakeholders to develop guidelines that promote the responsible and ethical use of AI while fostering innovation. Balancing the rapid evolution of AI capabilities with regulatory oversight presents a significant challenge in ensuring patient safety and ethical standards.

The future of AI in clinical trials and patient care holds immense potential for revolutionizing healthcare delivery and advancing pharmaceutical research. Embracing collaboration, ethical considerations, and ongoing innovation will be pivotal in overcoming the anticipated challenges and harnessing the full scope of AI's transformative impact on healthcare.

**CONCLUSION:**

In conclusion, the integration of AI in patient care presents significant opportunities for improving healthcare delivery, patient outcomes, and overall efficiency. By leveraging patient-specific data and predictive analytics, AI facilitates personalized treatment strategies, proactive healthcare interventions, and enhanced patient engagement. The future scope of AI in clinical trials and patient care holds promise in advancing precision medicine, predictive and preventive healthcare, and the integration of multi-omics data for accelerated therapeutic discoveries.

However, several challenges need to be addressed to ensure the responsible and beneficial integration of AI in patient care. These challenges include maintaining data privacy and security, addressing algorithmic bias and interpretability, and establishing adaptable regulatory and ethical frameworks to keep pace with the rapid evolution of AI technologies in healthcare.

Collaboration between healthcare providers, technology developers, regulatory bodies, and policymakers is crucial in establishing clear guidelines for the ethical and responsible use of AI in patient care. Embracing ethical considerations, ongoing innovation, and robust data governance frameworks will be pivotal in overcoming the anticipated challenges and harnessing the full scope of AI's transformative impact on healthcare.

**DECLARATIONS**

**Ethics approval and consent to participate:** Not applicable

**Consent for publication:** All authors give consent for the publication of review article.

**Availability of data and material:** Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

**Competing interests:** None

**Funding:** This review work was not supported by any funding.

**Authors' contributions:** Dr. Ashish Kumar Parashar conceptualize and written the review. Dr. Lalit Kumar Tyagi analyzed the content of the article and Dr. Vandana Arora supervised the review process and writing. All authors read and approved the final manuscript.

**Acknowledgements:** The authors appreciate Dr. Vandana Arora for her valuable input and guidance in the preparation of this review article. We would also like to acknowledge the support provided by Lloyd Institute of Management and Technology, Greater Noida.

**REFERENCES:**

1. Kirkpatrick, P J. (2022, May 17). Artificial intelligence makes a splash in small-molecule drug discovery. https://doi.org/10.1038/d43747-022-00104-7
2. Drug Discovery and Development Archives. (2023, February 1). https://www.drugdiscoverytrends.com/category/drug-discovery-and-development/
3. Schork, N J. (2012, January 1). Artificial Intelligence and Personalized Medicine. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7580505/
4. Curth, A. (2023, December 20). Using Machine Learning to Individualize Treatment Effect Estimation: Challenges and Opportunities. https://ascpt.onlinelibrary.wiley.com/doi/10.1002/cpt.3159
5. Increasing Diversity In Clinical Trials: The Critical Role Of Community Partnerships & Collaborations. (2023, January 1). https://www.clinicalleader.com/doc/increasing-diversity-in-clinical-trials-the-critical-role-of-community-partnerships-collaborations-0001.
6. HealthCare App Development Company - MobileCoderz. (2020, January 1). https://mobilecoderz.com/healthcare-app-development
7. Silcox, C., Zimlichmann, E., Huber, K., Rowen, N., Saunders, R., McClellan, M., Kahn, C. N., III, Salzberg, C. A., & Bates, D. W. (2024). The potential for artificial intelligence to transform healthcare: perspectives from international health leaders. Npj Digital Medicine, 7(1). https://doi.org/10.1038/s41746-024-01097-6
8. Reddy, S., Allan, S., Coghlan, S., & Cooper, P. (2020). A governance model for the application of AI in health care. Journal of the American Medical Informatics Association: JAMIA, 27(3), 491–497. https://doi.org/10.1093/jamia/ocz192
9. Paul, D., Sanap, G., Shenoy, S., Kalyane, D., Kalia, K., & Tekade, R. K. (2021). Artificial intelligence in drug discovery and development. Drug Discovery Today, 26(1), 80–93. https://doi.org/10.1016/j.drudis.2020.10.010
10. Vora, L. K., Gholap, A. D., Jetha, K., Thakur, R. R. S., Solanki, H. K., & Chavda, V. P. (2023). Artificial intelligence in pharmaceutical technology and drug delivery design. Pharmaceutics, 15(7), 1916. https://doi.org/10.3390/pharmaceutics15071916
11. Alowais, S. A., Alghamdi, S. S., Alsuhebany, N., Alqahtani, T., Alshaya, A. I., Almohareb, S. N., Aldairem, A., Alrashed, M., Bin Saleh, K., Badreldin, H. A., Al Yami, M. S., Al Harbi, S., & Albekairy, A. M. (2023). Revolutionizing healthcare: the role of artificial intelligence in clinical practice. BMC Medical Education, 23(1). https://doi.org/10.1186/s12909-023-04698-z
12. Shah, P., Kendall, F., Khozin, S., Goosen, R., Hu, J., Laramie, J., Ringel, M., & Schork, N. (2019). Artificial intelligence and machine learning in clinical development: a

translational perspective. Npj Digital Medicine, 2(1), 1–5. https://doi.org/10.1038/s41746-019-0148-3

13. Arasteh, S T., Ziller, A., Kuhl, C., Makowski, M R., Nebelung, S., Braren, R., Rueckert, D., Truhn, D., & Kaissis, G. (2024, March 14). Preserving fairness and diagnostic accuracy in private large-scale AI models for medical imaging. https://doi.org/10.1038/s43856-024-00462-6
14. Colijn, C., Jones, N., Johnston, I G., Yaliraki, S N., & Barahona, M. (2017, March 21). Toward Precision Healthcare: Context and Mathematical Challenges. https://doi.org/10.3389/fphys.2017.00136
15. Evers, A W M., Rovers, M M., Kremer, J., Veltman, J A., Schalken, J A., Bloem, B., & Gool, A J V. (2012, August 1). An integrated framework of personalized medicine: from individual genomes to participatory health care. https://doi.org/10.3325/cmj.2012.53.301
16. Everson, J., Smith, J M., Marchesini, K., & Tripathi, M. (2024, February 28). A Regulation To Promote Responsible AI In Health Care. https://doi.org/10.1377/forefront.20240223.953299
17. Perni, S., Lehmann, L. S., & Bitterman, D. S. (2023). Patients should be informed when AI systems are used in clinical trials. Nature Medicine, 29(8), 1890–1891. https://doi.org/10.1038/s41591-023-02367-8
18. Freedman, D. H. (2019). Hunting for new drugs with AI. Nature, 576(7787), S49–S53. https://doi.org/10.1038/d41586-019-03846-0
19. Daly, C. (2018, March 6). The Empathy Gap: Designing Intelligent Healthcare Systems. https://aibusiness.com/verticals/the-empathy-gap-designing-intelligent-healthcare-systems
20. London, A J. (2022, May 1). Artificial intelligence in medicine: Overcoming or recapitulating structural challenges to improving patient care?. https://doi.org/10.1016/j.xcrm.2022.100622
21. Sivaraman, V., Bukowski, L., Levin, J., Kahn, J M., & Perer, A. (2023, April 19). Ignore, Trust, or Negotiate: Understanding Clinician Acceptance of AI-Based Treatment Recommendations in Health Care. https://doi.org/10.1145/3544548.3581075
22. Golden, G., Popescu, C., Israel, S., Perlman, K., Armstrong, C., Fratila, R., Tanguay-Sela, M., & Benrimoh, D. (2024, January 1). Applying artificial intelligence to clinical decision support in mental health: What have we learned?. https://doi.org/10.1016/j.hlpt.2024.100844
23. Nordling, L. (2019, September 25). A fairer way forward for AI in health care. https://doi.org/10.1038/d41586-019-02872-2
24. Chen, I Y., Joshi, S., & Ghassemi, M. (2020, January 1). Treating health disparities with artificial intelligence. https://doi.org/10.1038/s41591-019-0649-2
25. Sadeghi, Z., Alizadehsani, R., Cifci, M. A., Kausar, S., Rehman, R., Mahanta, P., Bora, P. K., Almasri, A., Alkhawaldeh, R. S., Hussain, S., Alatas, B., Shoeibi, A., Moosaei, H., Hladik, M., Nahavandi, S., & Pardalos, P. M. (2023). A brief review of explainable

artificial intelligence in healthcare. In arXiv [cs.AI]. https://deepai.org/publication/a-brief-review-of-explainable-artificial-intelligence-in-healthcare

26. Qattan, M Y., Demonacos, C., & Krstic-Demonacos, M. (2012, August 1). Roadmap to personalized medicine. https://doi.org/10.3325/cmj.2012.53.294
27. Nakayama, L F., Kras, A., Ribeiro, L Z., Malerbi, F K., Mendonça, L S., Celi, L A., Regatieri, C V., & Waheed, N K. (2022, April 1). Global disparity bias in ophthalmology artificial intelligence applications. https://doi.org/10.1136/bmjhci-2021-100470
28. Goldberg, C. B., Adams, L., Blumenthal, D., Brennan, P. F., Brown, N., Butte, A. J., Cheatham, M., deBronkart, D., Dixon, J., Drazen, J., Evans, B. J., Hoffman, S. M., Holmes, C., Lee, P., Manrai, A. K., Omenn, G. S., Perlin, J. B., Ramoni, R., Sapiro, G., … the RAISE Consortium. (2024). To do no harm — and the most good — with AI in health care. Nature Medicine, 30(3), 623–627. https://doi.org/10.1038/s41591-024-02853-7
29. Qureshi, R., Irfan, M., Gondal, T M., Khan, S., Wu, J., Hadi, M U., Heymach, J V., Le, X., Yan, H., & Alam, T. (2023, July 1). AI in drug discovery and its clinical relevance. https://doi.org/10.1016/j.heliyon.2023.e17575
30. Sadybekov, A., & Katritch, V. (2023, April 26). Computational approaches streamlining drug discovery. https://doi.org/10.1038/s41586-023-05905-z
31. Hopper, L. (2023, April 27). How AI might speed up the discovery of new drugs. https://phys.org/news/2023-04-ai-discovery-drugs.html
32. Réda, C., Kaufmann, E., & Delahaye-Duriez, A. (2020, January 1). Machine learning applications in drug development. https://doi.org/10.1016/j.csbj.2019.12.006
33. Renfro, L A., Mallick, H., An, M., Sargent, D J., & Mandrekar, S J. (2016, February 5). Clinical trial designs incorporating predictive biomarkers.. https://cancertreatmentreviews.com/retrieve/pii/S0305737215002546
34. Mock, M., Edavettal, S C., Langmead, C J., & Russell, A J. (2023, September 19). AI can help to speed up drug discovery — but only if we give it the right data. https://doi.org/10.1038/d41586-023-02896-9
35. Panch, T., Mattie, H., & Atun, R. (2019, November 24). Artificial intelligence and algorithmic bias: implications for health systems. https://doi.org/10.7189/jogh.09.020318
36. Rosenberger, S. (2023, January 1). Growth of Artificial Intelligence in Pharma Manufacturing. https://doi.org/10.1089/gen.43.01.12
37. Mishra, M., Prasad, K., Eshkalak, S K., & Jha, A K. (2023, June 25). Nanomaterials in drug delivery—Promises and limitations. https://doi.org/10.59400/nmm.v3i1.38
38. Hwang, R., & Noack, R M. (2011, January 1). Application of design of experiments to pharmaceutical formulation development. https://doi.org/10.1504/ijedpo.2011.038051
39. Lane, M E., Hadgraft, J., Oliveira, G., Vieira, R., Mohammed, D., & Hirata, K. (2012, September 1). Rational formulation design. https://doi.org/10.1111/j.1468-2494.2012.00747.x

40. Narang, A S., Delmarre, D., & Gao, D. (2007, September 8). Stable drug encapsulation in micelles and microemulsions.. https://www.sciencedirect.com/science/article/pii/S037851730700751X
41. Savage, N. (2021, May 27). Tapping into the drug discovery potential of AI. https://doi.org/10.1038/d43747-021-00045-7
42. Mehta, C H., Narayan, R., & Nayak, U Y. (2019, March 5). Computational modeling for formulation design. https://www.sciencedirect.com/science/article/pii/S1359644618303325
43. Silcox, C., Zimlichmann, E., Huber, K., Rowen, N P., Saunders, R S., McClellan, M., Kahn, C N., Salzberg, C., & Bates, D W. (2024, April 9). The potential for artificial intelligence to transform healthcare: perspectives from international health leaders. https://doi.org/10.1038/s41746-024-01097-6
44. Fountzilas, E., Tsimberidou, A M., Vo, H H., & Kurzrock, R. (2022, August 31). Clinical trial design in the era of precision medicine. https://doi.org/10.1186/s13073-022-01102-1
45. Singer, E. (2005, May 1). Personalized medicine prompts push to redesign clinical trials. https://doi.org/10.1038/nm0505-462a
46. Chen, W., Li, R., Yu, Q., Xu, A., et al. (2023, January 26). Early detection of visual impairment in young children using a smartphone-based deep learning system. https://doi.org/10.1038/s41591-022-02180-9
47. Wang, Y., Yang, K., Wen, Y., et al. (2024, May 13). Screening and diagnosis of cardiovascular disease using artificial intelligence-enabled cardiac magnetic resonance imaging. https://doi.org/10.1038/s41591-024-02971-2
48. Krishnankutty, B., Kumar, B N., Moodahadu, L S., & Bellary, S. (2012, January 1). Data management in clinical research: An overview. https://doi.org/10.4103/0253-7613.93842
49. Gianfrancesco, M., Tamang, S., Yazdany, J., & Schmajuk, G. (2018, November 1). Potential Biases in Machine Learning Algorithms Using Electronic Health Record Data. https://doi.org/10.1001/jamainternmed.2018.3763
50. Dave, M., & Patel, N. (2023, May 26). Artificial intelligence in healthcare and education. https://doi.org/10.1038/s41415-023-5845-2
51. Khalifa, M., Albadawy, M., & Iqbal, U. (2024, January 1). Advancing Clinical Decision Support: The Role of Artificial Intelligence Across Six Domains. https://doi.org/10.1016/j.cmpbup.2024.100142
52. Hosny, A., Parmar, C., Quackenbush, J., Schwartz, L H., & Aerts, H J. (2018, May 17). Artificial intelligence in radiology. https://doi.org/10.1038/s41568-018-0016-5
53. Pesapane, F., Codari, M., & Sardanelli, F. (2018, October 24). Artificial intelligence in medical imaging: threat or opportunity? Radiologists again at the forefront of innovation in medicine. https://doi.org/10.1186/s41747-018-0061-6
54. Li, R., Zhang, P., Barker, L., Chowdhury, F M., & Zhang, X. (2010, August 1). Cost-Effectiveness of Interventions to Prevent and Control Diabetes Mellitus: A Systematic Review. https://doi.org/10.2337/dc10-0843

55. Diehr, P., Derleth, A., Cai, L., & Newman, A B. (2007, April 5). The effect of different public health interventions on longevity, morbidity, and years of healthy life. https://doi.org/10.1186/1471-2458-7-52
56. Mittermaier, M., Raza, M M., & Kvedar, J C. (2023, June 14). Bias in AI-based models for medical applications: challenges and mitigation strategies. https://doi.org/10.1038/s41746-023-00858-z
57. Zhang, J., & Zhang, Z. (2023, January 13). Ethics and governance of trustworthy medical artificial intelligence. https://doi.org/10.1186/s12911-023-02103-9