Intelligent Pharma: Exploring AI's Impact and Future Frontiers

Prema Rathinam[1], Senthilkumar Chelladurai[2], Khalidha Banu Sheik Abdulla[3], Sabitha Rajamanickam[4], Chandrasekharan Padmanaban[5], Mageshwari Rajendran[6], Manju Subramanian[7]

[1, 2] Department of Pharmaceutics, Sir Issac Newton College of Pharmacy, Nagapattinam, Tamilnadu

[3,7] Department of Pharmaceutics, Cherrans College of Pharmacy, Coimbatore, Tamilnadu

[4] Department of Pharmaceutics, School of Pharmacy, Dhanalakshmi Srinivasan University, Trichy, Tamilnadu

[5] Department of Pharmaceutics, Shree Krishna College of Pharmacy, Chengam, Tamilnadu

[6] Department of pharmacology, Sree bhavani College of Pharmacy, Veppur, Cuddalore, Tamilnadu

Corresponding Author:
Dr. R. Prema, M. Pharm., Ph.D., L.L.B.,
Professor/IQAC Director
Department of Pharmaceutics
Sir Issac Newton College of Pharmacy
Nagapattinam
Tamilnadu.

Abstract:

Artificial Intelligence (AI) is changing the pharmaceutical industry by greatly improving how drugs are discovered, developed, and used in patient care. AI methods like machine learning, natural language processing, and deep learning are being used from the very start of drug development to monitoring medicines after they are released to the market. In pharmacy settings, AI helps make better clinical decisions, enhances patient health, minimizes mistakes with medication, and improves the efficiency of both hospitals and community pharmacies. In the area of research and development, AI-based systems speed up the search for potential drugs, forecast how drugs will behave in the body, and help create personalized treatment plans using genetic information and real-world data. This review seeks to thoroughly examine how AI is being applied in pharmaceutical sciences. It looks into the current methods, including different AI models and systems, discusses how they are being used in areas like drug discovery, clinical trials, how drugs are made, and safety monitoring, and emphasizes real-life uses and regulatory hurdles. Additionally, the review considers ethical issues and discusses future possibilities, including how AI could transform drug innovation and healthcare services.

Keywords: Artificial Intelligence, Drug Discovery, Formulation Development, Process Optimization, Clinical Decision Support, Pharmacovigilance and Personalized Medicine.

Introduction

The drug industry is using Artificial Intelligence (AI) more and more to tackle the difficult, costly, and time-consuming aspects of making new medicines. AI techniques such as machine learning (ML), natural language processing (NLP), and deep learning have demonstrated positive outcomes in pharmaceutical research, production, and clinical settings. This article looks at the present state of AI in the field of pharmacy, focusing on its contributions to innovation, effectiveness, and decision-making. Pharmacy, which is a vital part of healthcare, is experiencing a major change with the introduction of Artificial Intelligence (AI). The growth of data-driven approaches and strong computing capabilities has allowed AI to play a role in developing drugs, taking care of patients, and managing medications. The use of AI not only aims to improve efficiency and precision but also helps in creating personalized medicine and lowering healthcare expenses. This article points out important uses of AI in pharmacy practice and pharmaceutical sciences.

Methodology

This assessment is founded on an extensive search of existing literature carried out using databases such as PubMed, ScienceDirect, and arXiv. Works released from 2018 to 2025 were looked at, concentrating on the use of AI in areas like finding new drugs, clinical pharmacy, drug safety monitoring, following medication instructions, and automating pharmacy tasks. The criteria for choosing articles included their importance, whether they had been reviewed by peers, and the availability of data. The selection included both research studies and review papers.

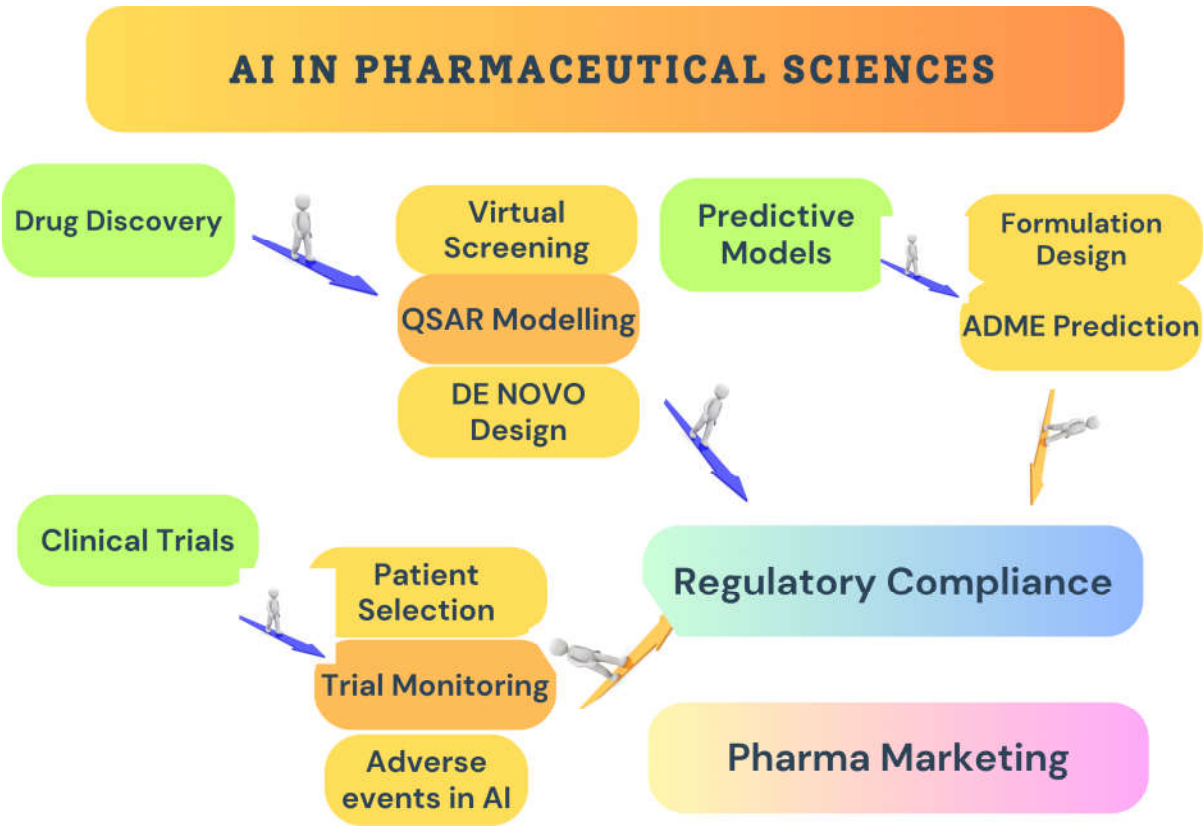

Figure: 1 - Applications of AI in Pharmaceutical sciences

Drug Discovery and Development

AI speeds up the process of finding new medicines by examining large amounts of data to spot potential drug options, foresee how molecules will interact, and evaluate if they are similar enough to drugs. Methods like deep learning and generative models allow for quick testing and creation of new compounds[1,2]. AI also helps in finding new uses for current medications, providing cheaper solutions[3].

AI improves the process of finding new drugs at the beginning stages by assisting with:

- Finding targets through genetic and protein information

- Virtual testing and refining promising options

- Creating models that relate structure to activity

These methods greatly shorten the time and expenses needed to find potential drug candidates[4,5]..

Preclinical Development

Models that use machine learning aid in forecasting:

- Toxicity results

- How drugs move through the body and their effects

- Unintended effects on other targets

By modeling how biological systems work, AI lessens the requirement for large-scale studies in living organisms and enhances the choice of candidates[6,7].

Clinical Decision Support Systems (CDSS)

AI-based CDSS helps pharmacists make informed choices about how drugs might interact, how much to give, and how to monitor treatments. These systems help prevent medication mistakes and improve patient safety[8,9]. Places like the Cleveland Clinic and Mayo Clinic have seen remarkable improvements in managing antibiotics and lowering readmission rates thanks to AI tools[10].

Formulation and Product Development

AI-based models are being used more and more for:

- Figuring out if excipients work well together

- Improving controlled-release formulations

- Applying quality-by-design principles

Predictive tools that use neural networks are useful for creating strong formulations and boosting manufacturing processes[11].

Process Analytical Technology (PAT) and Manufacturing

AI is essential in:

- Monitoring processes in real-time with spectral data such as NIR and Raman

- Controlling processes and spotting issues

- Performing predictive maintenance on machines

These uses help make batches more consistent, lower variability, and reduce downtime during production[12].

Clinical Trial Design and Optimization

AI supports clinical research by:

- Organizing patient groups using omics and electronic health record information

- Creating trial protocols automatically

- Anticipating when patients might drop out or face negative outcomes

AI-driven adaptive trial designs shorten development times and improve statistical effectiveness[13].

Pharmacovigilance:

AI systems that use natural language processing and machine learning can quickly identify harmful drug reactions by analyzing electronic health records, social media posts, and drug safety databases. These systems enhance early warning mechanisms and help regulators make informed decisions[14].

Regulatory Science and Pharmacovigilance

Regulatory agencies are investigating the use of AI for:

- Automated examination of applications and scientific studies

- Finding harmful drug reactions from social media and health records

- Models to assess risks and benefits

AI boosts monitoring after a drug is released by speeding up the detection and classification of issues[15,16].

Challenges and Ethical Considerations

- Inconsistent data and lack of transparency

- Uncertainty in regulations concerning AI tools

- Ethical issues related to privacy and bias in data

- Need for teamwork and training across different fields

To use AI responsibly, strong validation methods and worldwide agreement are crucial.

Personalized Medicine

AI combines information from genetics, physical traits, and lifestyle to customize medication for individual patients. Pharmacogenomic tools help determine the right dose and medication choices, which reduces side effects and improves effectiveness[17].

Pharmacy Operations and Automation

AI-based robotic systems and forecasting tools make dispensing, inventory control, and logistics more efficient. Hospitals in Asia and Europe have seen fewer dispensing mistakes and lower operational costs after using AI technologies[18].

Medication Adherence and Patient Engagement

Smart devices, virtual assistants, and chatbots powered by AI help patients stick to their prescribed treatments. These tools boost adherence by offering timely education and reminders[19].

Challenges and Limitations

Even though AI has great possibilities, using it in pharmacy comes with some difficulties:

- Concerns about data privacy and ethics
- Bias in algorithms and the need for clarity
- Absence of uniform standards and proof of effectiveness
- Inadequate digital infrastructure in places with fewer resources

To overcome these obstacles, a team effort from various fields, proper regulation, and ongoing studies are essential.

Table: 1 - Merits and Demerits of AI in Pharmaceutical Sciences

Speciality	Merits	Demerits
Drug Discovery	✓ Quicker lead detection ✓ Forecasts PK/PD ✓ lowers the price of research and development	✓ May depend on partial information ✓ Needs a lot of computing power
Drug Repurposing	✓ Discovers different applications for medication s that are already approved	✓ Requires carefully selected multi-omics and medical information
Clinical Trials	✓ Enhances the process of choosing patients ✓ Boosts the ability to attract sites	✓ Issues related to ethics and privacy ✓ Missing regulations
Precision Medicine	✓ Tailors therapy based on genes	✓ Risks to privacy and security of data

	✓ Enhances results of treatments	
Manufacturing	✓ Allows checking in real time ✓ Helps with maintenance before problems happen	✓ Difficult to combine with older systems
Pharmacovigilance	✓ NLP identifies negative occurrences from electronic health records and social media. ✓ There is a chance for incorrect positive results.	✓ The standard of data sources is inconsistent.
Model Transparency	—	✓ 'Black-box' models are hard to understand or clarify.
Regulatory Challenges	—	✓ Absence of universal AI rules in the pharmaceutical industry
Expenses and Expertise	—	✓ Significant upfront investment needed ✓ Needs skilled workers

Future Directions:

The use of Artificial Intelligence (AI) in the field of pharmacy is expected to grow a lot, marking the start of a new time for accuracy, effectiveness, and customized medicine development and pharmacy work. Here are some important areas that will influence how AI will be used in the future:

Creation of Understandable AI (XAI):

Standard AI systems, especially those that use deep learning, are often difficult to understand because they work like "black boxes," hiding how they reach their conclusions. The rise of understandable AI (XAI) aims to fix this problem by making AI results clearer and easier for healthcare workers and regulatory agencies to grasp. This clarity is vital for building trust, getting regulatory approval, and ensuring ethical use.

Merging with Health Tracking Devices and Remote Pharmacy Services:

The combination of AI with health tracking gadgets and remote pharmacy services offers chances for immediate data collection and distant pharmaceutical support. This teamwork could allow for ongoing patient observation, timely medication adjustments, and improved access, especially in areas that lack sufficient healthcare services or in rural communities.

Use of Digital Twins for Treatment Testing:

Digital twin technology creates unique virtual models that mimic how the body reacts to different treatments. By using data tailored to each patient, digital twins can help refine treatment plans, reduce side effects, and customize therapy for both medical and research purposes.

Growth of AI-Based Economic Models in Pharmacy:

AI is being more frequently utilized in healthcare economics to estimate the cost-effectiveness of medications, project treatment results, and aid decisions about resource distribution. These models can give leaders fact-based information for including drugs in lists, reimbursement decisions, and public health initiatives. To make sure these advancements are applied responsibly and fairly, we need to develop clear regulatory guidelines and have access to large, varied, and high-quality training data sets. Additionally, focusing on ethical issues, like reducing bias, ensuring data security, and promoting equal access, will be essential for defining the long-term impact of AI in the pharmaceutical field.

Conclusion

Artificial intelligence provides game-changing possibilities in various areas of pharmacy, starting from finding new drugs to getting them to patients. As technology keeps improving and is used wisely, AI can greatly enhance the quality, safety, and customization of medical services in the pharmaceutical field. Artificial intelligence has shown great promise in the field of pharmacy, covering everything from drug discovery to distribution. With the necessary systems, government backing, and teamwork across different fields, AI will persist in pushing forward new ideas and better effectiveness in developing medicines and delivering healthcare services.

References:

1. Chalasani M, et al. Artificial intelligence in the field of pharmacy practice: A literature review. Pharmacy Practice. 2023; 21(2): 2965.
2. Nori H, et al. Explainable AI for drug discovery and development. arXiv. 2023. Available from: https://arxiv.org/abs/2309.12177
3. Santosh KC. Artificial intelligence in drug discovery and development. Int J Pharm Sci. 2023; 7(4): 128 - 36.
4. Chen H, Engkvist O, Wang Y, Olivecrona M, Blaschke T. The rise of deep learning in drug discovery. Drug Discov Today. 2018; 23(6): 1241 - 1250.
5. Zhavoronkov A, Ivanenkov YA, Aliper A, et al. Deep learning enables rapid identification of potent DDR1 kinase inhibitors. Nat Biotechnol. 2019; 37(9): 1038 - 1040.
6. Vamathevan J, Clark D, Czodrowski P, et al. Applications of machine learning in drug discovery and development. Nat Rev Drug Discov. 2019; 18(6): 463 - 477.
7. Lee S, Kim J, Choi Y, et al. Prediction of in vivo drug interactions and toxicity with deep learning. Sci Rep. 2020; 10(1): 9065.

8. Botsis T, Nguyen MD, Woo EJ, Markatou M, Ball R. Text mining for the Vaccine Adverse Event Reporting System: medical text classification using informative feature selection. J Am Med Inform Assoc. 2011; 18(5): 631 - 638.

9. US FDA. Artificial Intelligence and Machine Learning in Software as a Medical Device. 2021.

10. Simpson J, Qasim A. Clinical and operational applications of artificial intelligence in pharmacy. Pharmacy. 2025; 13(2): 41.

11. Shinde A, Narayan R, Vavia PR. Artificial intelligence in pharmaceutical product design. Drug Dev Ind Pharm. 2020; 46(11): 1761 - 1769.

12. Nasr MM, Felton LA, Qiu Y. Real-time release testing: Current status and future trend. J Pharm Sci. 2020; 109(2): 494 - 500.

13. Collins FS, Varmus H. A new initiative on precision medicine. N Engl J Med. 2015; 372(9): 793 - 795.

14. Hussein R, et al. Integration of AI into hospital pharmacy systems: A Saudi experience. Saudi Pharm J. 2024; 32(1): 22 - 8.

15. Vaidya A, et al. Impact of AI-powered pharmacy automation on dispensing errors and time efficiency. Pharm Technol Hosp Pharm. 2023; 8(3): 150 - 7.

16. Mehta D, et al. Use of AI in improving medication adherence: A review. Pharm Pract (Granada). 2024; 22(1): 3201.

17. Mottaghi-Dastjerdi N, Soltany-Rezaee-Rad M. Artificial Intelligence Applications in Pharmaceutical Sciences and Technology. Iran J Pharm Res. 2024; 23(1): e150510.

18. Zhang S, et al. PharmacyGPT: A large language model for medication therapy management. arXiv. 2023. Available from: https://arxiv.org/abs/2307.10432

19. US FDA. Artificial Intelligence & Machine Learning (AI/ML)-Enabled Medical Devices. U.S. Food and Drug Administration. 2025.