

REVOLUTIONIZING PHARMACEUTICALS WITH ARTIFICIAL INTELLIGENCE: A REVIEW

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ABSTRACT

Artificial intelligence (AI) emerged in the 1950s, with Alan Turing's concept of machine intelligence and John McCarthy's formal definition in 1956. Since then, AI has evolved from basic rule-based systems to advanced techniques like Machine Learning (ML), Deep Learning (DL), and Computer Vision (CV), enabling machines to learn from data, recognise patterns, and make autonomous decisions. AI has significantly impacted healthcare and pharmaceuticals, improving diagnostic accuracy, workflow efficiency, and personalised care. It transforms various pharmacy domains, including drug delivery systems, formulation development, and drug discovery. Techniques such as Principal Component Analysis (PCA), Support Vector Machines (SVM), neuro-fuzzy logic, and Artificial Neural Networks (ANN) are often used to create predictive models. AI platforms like DeepChem, REINVENT, and AlphaFold have accelerated drug discovery by aiding in molecular design and predicting protein-ligand interactions. Additionally, AI enhances drug delivery by improving dissolution rates and increasing bioavailability. In clinical settings, tools like IBM Watson and Google DeepMind support decision-making and data management. While AI innovations enable rapid discovery and patient-centred strategies, they also raise ethical concerns and may redefine the roles of pharmacists in modern healthcare.

KEYWORDS: Artificial Intelligence, Healthcare, Pharmaceuticals, Machine Learning, Computer Vision, Human Intelligence, Drug Discovery, Neurofuzzy logic, IBM Watson, Google DeepMind.

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INTRODUCTION

This review paper examines how Artificial Intelligence (AI) has contributed to advancements in the pharmaceutical industry, highlighting its recent applications, advantages, disadvantages, and the challenges faced during implementation in the current landscape. To set the context, it is important to understand the present state of the pharmaceutical industry. This sector plays a critical role in enhancing global healthcare, yet it grapples with significant structural and economic challenges. Despite rapid advancements in science and technology, the processes of drug discovery and development have become increasingly inefficient, costly, and time consuming. The average expense associated with developing a new drug has surged from approximately US\$800 million in 2001 to over US\$3 billion today. This increase can be attributed primarily to high failure rates and stringent regulatory requirements. Typically, only one in nine drug candidates that enter clinical development ultimately receives regulatory approval.^[1] These constraints have heightened the demand for innovative technologies that can enhance efficiency, lower costs, and boost the likelihood of success. In recent years, Artificial Intelligence (AI) has emerged as one of the most transformative technologies, possessing the potential to fundamentally reshape the pharmaceutical industry.

1.1 ARTIFICIAL INTELLIGENCE (AI)

Artificial Intelligence is a computational system designed to perform tasks that typically require human intelligence, such as learning, reasoning, pattern recognition, and decisionmaking.^[2] Artificial Intelligence (AI) focuses on programming computers to think and act like humans. The concept began in the 1950s and 1960s when Alan Turing asked, "*Can machines think?*" John McCarthy later coined the term "Artificial Intelligence." Over the past sixty years, AI has evolved from simple "if this, then that" rules to advanced systems capable of learning and reasoning. In pharmaceuticals, AI operates through sub-disciplines like Machine Learning (ML), Deep Learning (DL), and Natural Language Processing (NLP), allowing for the analysis of complex datasets from chemical libraries, biological assays, clinical trials, and electronic health records.^[3] The integration of AI into pharmaceutical workflows has introduced a new era, shifting from empirical, trial-and-error approaches to data-driven and predictive models, offering new opportunities across the entire drug life cycle.

1.2 AI in Drug Discovery

One of the most impactful applications of AI in the pharmaceutical industry is drug discovery. AI has proven capable of significantly speeding up the process of identifying drug targets and selecting promising molecules with therapeutic potential

from large chemical libraries through compound screening and molecular optimisation. Traditional drug discovery is a lengthy and complex process that relies heavily on high-throughput screening and experimental validation, which are both time-consuming and resource-intensive. In contrast, AI-based models can quickly analyse millions of chemical structures, predict drug-target interactions, and estimate pharmacokinetic and toxicological properties through *in silico* methods.^[4] These methods greatly lower early-stage attrition and help researchers prioritise the most promising candidates for experimental testing. Importantly, AI systems like AlphaFold have transformed protein structure prediction, achieving exceptional accuracy and enhancing structure-based drug design.^[5]

1.3 AI in Drug Development and Clinical Trials

Beyond discovery, artificial intelligence is playing an increasingly significant role in drug development and clinical trials, sectors that have historically faced inefficiencies leading to high failure rates. Delays in clinical trials often arise from challenges related to patient recruitment, protocol design and outcome monitoring. AI-driven analytics can enhance trial design by identifying appropriate patient populations, predicting treatment responses and improving adherence through digital monitoring tools.^[6] Machine learning models can analyze real-world data to enhance clinical trial findings, supporting adaptive trial designs and postmarketing surveillance.^[7] As a result, AI has the potential to enhance trial success rates while reducing the development timelines and costs.

1.4 AI in Pharmaceutical Manufacturing and Quality Control.

AI technologies are revolutionising quality control and pharmaceutical manufacturing. Advanced algorithms can be employed for real-time quality monitoring, predictive maintenance, and process optimisation to ensure consistent product quality and regulatory compliance.^[8] By predicting demand, reducing waste, and enhancing operational efficiency, AI-powered automation significantly improves supply chain management. This is particularly crucial during global health emergencies when timely and reliable drug production is vital.

1.5 AI in Pharmacovigilance and Personal Medicine.

Pharmacovigilance and personalised medicine are rapidly expanding fields. Traditional pharmacovigilance systems often depend on voluntary reporting, which can lead to delays in detecting adverse drug reactions. To identify safety signals in real time, AI-driven natural language processing (NLP) tools can analyse vast amounts of clinical reports, social media data, and electronic health records.^[9] Additionally, AI helps

personalised medicine by combining clinical, proteomic, and genomic data to customise treatments for each patient, increasing treatment effectiveness and reducing side effects.^[10]

1.6 AI in Anti-Dengue Drug Development.

Dengue fever is a rapidly spreading mosquito-borne viral disease caused by four distinct serotypes of dengue viruses (DENV), representing a significant global public health challenge due to the lack of FDA-approved antiviral therapies and the limited effectiveness of current vaccines.

Artificial intelligence (AI) has emerged as a transformative tool in anti-dengue drug development, facilitating the rapid analysis of biological, chemical, and immunological data. AI-driven methods, such as machine learning, QSAR modelling, molecular docking, and virtual screening, are increasingly used to identify and optimise potential dengue virus inhibitors. These approaches have led to the discovery of antiviral candidates from natural products and synthetic compounds. AI-assisted drug repurposing has also been effective in identifying FDA-approved drugs with anti-dengue activity, accelerating therapeutic development. Furthermore, AI has been applied to analyse dengue immune repertoires and predict virus-host protein interactions, aiding in the identification of novel antibody-based therapies and supporting vaccine design. Overall, integrating AI into dengue research offers a promising and efficient strategy to enhance antiviral discovery and improve dengue infection management.^[11]

1.7 AI in Cancer Imaging.

Artificial intelligence (AI) is transforming cancer imaging by improving the accuracy and efficiency of detection, diagnosis, and treatment monitoring. By applying machine learning and deep learning techniques to modalities like CT, MRI, PET, ultrasound and digital pathology, AI enhances tumour detection, segmentation, and characterisation. AI-driven radiomics also supports personalised medicine by linking imaging features with tumour biology and treatment response. Additionally, AI streamlines clinical workflows, reducing the workload on radiologists and minimising interpretation variability. However, challenges such as data standardisation and regulatory approval still impede widespread adoption. Overall, AI shows great potential for advancing precision oncology and improving patient outcomes.^[12] While the adoption of AI in pharmaceuticals holds significant promise for transformation, it also faces considerable challenges. Key barriers include data quality, availability, and standardisation, as biased or incomplete datasets can result in inaccurate predictions and diminished generalizability. Additionally, ethical concerns surrounding data privacy, algorithmic

transparency, and accountability further complicate the implementation of these technologies. Regulatory agencies are in the process of developing frameworks to evaluate and approve AI-driven tools, underscoring the need for clear guidelines that strike a balance between fostering innovation and ensuring patient safety.^[14]

The rapid advancement of AI technologies in pharmaceutical sciences calls for a concise review of their applications, benefits, limitations, and prospects. This analysis will examine how artificial intelligence is transforming the pharmaceutical industry, summarising recent research findings and highlighting key challenges for responsible and sustainable integration.

1. RECENT IMPLEMENTATION

The pharmacy industry is currently experiencing significant changes due to the rapid evolution of Artificial Intelligence (AI). AI is transforming various aspects of the pharmacy profession, including drug development, clinical trials, pharmacy management, and patient care.^[7] With the aid of AI technology, the process of drug development has become faster and more efficient. This enables effective management of medications and the development of personalised treatment plans for individual patients.^[10]

Consequently, pharmacy services are becoming more efficient, cost-effective, and time saving. AI technology assists in reducing workloads, increasing efficiency, and improving decision-making in healthcare environments.^[15] The integration of Artificial Intelligence in the healthcare sector has the potential to significantly enhance patient outcomes and the overall quality of care. However, this growing use of AI technology also presents challenges related to data privacy, ethical data utilisation, regulatory compliance, and the necessity for proper training of pharmacists.^[16] However, to overcome these challenges, it is important to formulate proper regulatory policies and guidelines for the application of Artificial Intelligence in pharmacy practice. With proper application, Artificial Intelligence will not be a replacement for human knowledge but will become a useful tool in pharmacy practice.^[10]

AI is an important area not only in the clinical and operational aspects of pharmacy but also in pharmaceutical technology. It makes a significant contribution to drug discovery, formulation, and drug delivery system design.^[8] Artificial Intelligence and Machine Learning are widely utilised for target identification, molecular optimisation, and virtual screening to determine the most suitable dosage form.^[4] These tools can also predict pharmacokinetics and pharmacodynamics, enabling scientists to understand how drugs work in the human body.

This is necessary for the development of safe and effective drugs. The main objective is to make the drug development process quicker, more precise, and less reliant on trial-and-error approaches, thus lowering the total cost.^[7]

Moreover, AI is very helpful in the design of novel drug delivery systems, such as oral formulations, injectables, nanoparticles and biologics. It also assists in computer-aided drug design and 3D printing of drugs, which is a new area in personalised medicine.^[8] There are, however, some reservations regarding the integration of AI with traditional pharmaceutical knowledge. AI should be viewed as an auxiliary tool that enhances the capabilities of pharmacists rather than replacing their professional expertise. The collaboration between pharmacists and AI has the potential to improve accuracy, efficiency, and patient outcomes.^[16] The drug development industry is moving at a fast pace owing to the growing adoption of artificial Intelligence in data analysis. Machine Learning and Deep Learning techniques, which are AI-based, are highly efficient in analysing large-scale healthcare data.^[15] These techniques are used in disease prediction, drug development, and customised healthcare planning. AI-assisted data analysis helps healthcare professionals and researchers take more accurate and evidence-based decisions. Moreover, predictive models developed using AI are enhancing the accuracy and reliability of drug development and treatment plans.^[6]

However, there are still some challenges in the use of AI in data analysis, such as data integration problems, the absence of standardised datasets, data reliability problems, and data quality maintenance. These problems need to be overcome to ensure the successful application of AI in pharmaceutical research.^[8]

The strategic use of Artificial Intelligence in data analysis holds the promise of transforming the healthcare and pharmaceutical industries in the years ahead. AI and big data analytics are set to significantly enhance drug development and optimise healthcare delivery systems.^[7] In the current technological age, Artificial Intelligence is playing a major role in the design of new medicines and novel drug delivery systems. AI assists in target identification, virtual screening, formulation design, and analysis of drug-body interactions.^[4] AI has been used in various drug delivery systems like oral medications, injectables, nano-formulations, biologics, and 3D-printed pharmaceuticals.^[8] Thus, AI should be considered a revolutionary technology that supports drug delivery research and does not replace traditional research methods. Furthermore, Artificial Intelligence is accelerating the drug repurposing process, especially during global health crises such as the COVID-19 pandemic.

Drug development is traditionally known to be time-consuming, expensive and often fraught with failures. In contrast, drug repurposing offers a quicker and more cost-effective alternative.^[17] Various drugs like hydroxychloroquine, remdesivir, lopinavir/ritonavir and tocilizumab were explored for their potential use in different therapeutic areas with the help of AI-driven computational models during the pandemic. ^[4] Although AI-assisted drug development is a relatively new area, it holds immense promise because of its speed, cost-effectiveness, and ability to process complex biological data. AI-assisted methods are able to optimise drug development and repurpose existing drugs more effectively than traditional methods. ^[17]

In addition to research and development, artificial intelligence has made significant contributions to various aspects of the pharmaceutical industry, including pharmacovigilance, clinical research, medical affairs, and pharmaceutical marketing. Techniques such as machine learning and natural language processing (NLP) are utilised to manage vast amounts of data, identify adverse drug reactions, and streamline clinical trial management.^[9] The pharmaceutical industry is currently facing significant challenges, which includes high costs of drug development, long development timelines, and safety issues. AI-based automated systems help overcome these challenges by enhancing efficiency, accuracy and safety. ^[15]

The integration of Artificial Intelligence in pharmacovigilance and essential pharmaceutical processes presents a cost-effective and efficient solution to the challenges faced in the pharmaceutical industry. It enhances drug safety monitoring, streamlines clinical research, and boosts productivity, ultimately leading to the development of safer and more effective medications. ^[9]

2. ADVANTAGE OF ARTIFICIAL INTELLIGENCE IN THE PHARMACEUTICAL FIELD:

- a) **Medical Applications:** Artificial Intelligence systems assist doctors in accurately diagnosing conditions by analysing large data sets. They can identify potential adverse drug reactions, predict health risks and promote safer prescribing. Furthermore, AI surgical simulators allow young surgeons to practice complex procedures, boosting their skills and confidence while minimising human errors.
- b) **Comprehensive Role of AI in Healthcare:** AI systems play a vital role in healthcare, aiding in medical diagnosis, clinical decision support, precision medicine, patient care and health monitoring. By analysing patient histories, lab results and images, they can

assist healthcare professionals in making evidence-based decisions, transforming modern medical practices.

- c) **Enhanced Diagnosis and Treatment Outcomes:** AI technology enables swift and accurate diagnoses of a patient's condition by analysing medical images, laboratory results, and patient data. It can also reduce the likelihood of medical errors and assist doctors in making informed treatment decisions. Additionally, AI technology plays a significant role in advancing personalised medicine.
- d) **Enhanced Healthcare Efficiency:** AI enhances healthcare efficiency by improving diagnosis and treatment accuracy. It assists in medication risk assessment, provides surgical training through simulations and automates routine tasks, enabling healthcare professionals to focus more on patient care while maintaining accuracy.
- e) **Rapid and Cost-Effective Drug Discovery:** AI plays a crucial role in the swift discovery and development of medications. By predicting toxicity, pharmacokinetics, and efficacy at an early stage, it significantly reduces both time and costs. AI models facilitate the efficient identification of effective treatments, thereby lowering the likelihood of failure in clinical trials.
- f) **Introduction of Advanced AI Tools:** AI introduces advanced technologies such as Machine Learning, Deep Learning, and Natural Language Processing to the pharmaceutical industry. These innovations allow for the analysis of complex data, the extraction of insights from medical literature, and the automation of repetitive tasks, enhancing efficiency and operations.
- g) **Continuous Working Capability:** AI systems can operate continuously without experiencing fatigue or the need for breaks, functioning 24/7. This allows for uninterrupted monitoring, analysis, and decision support. Such constant vigilance makes AI systems highly valuable in the healthcare industry, where ongoing attention is crucial.
- h) **Reduced Risk in Hazardous Environments:** In high-risk environments like fire stations, chemical plants, or hazardous laboratories, human workers face significant safety hazards. AI-powered machines and robots can perform perilous tasks (extremely dangerous or hazardous), thereby minimising the risk of injury or fatality. Even in the event of errors, machine learning systems can be adjusted or

reprogrammed, whereas human mistakes can be irreversible.

- i) **Endless and Highly Accurate Performance:** AI systems do not have physical or mental limitations. They can process large amounts of data quickly and perform tasks with greater accuracy and efficiency than humans. This limitless capability makes AI an essential tool for complex tasks in the pharmaceutical and healthcare fields.

3. DISADVANTAGES OF ARTIFICIAL INTELLIGENCE IN THE PHARMACEUTICAL FIELD:

- a) **Lack of Emphasis on Cost:** The implementation of artificial intelligence (AI) technology in the pharmaceutical industry involves significant startup and operational costs. This technology requires advanced and costly hardware and software, along with ongoing software upgrades. As a result, low-income and middle-income hospitals and pharmaceutical companies may find it challenging to adopt AI technology on a large scale. Consequently, this can lead to unequal access to AI resources, potentially widening the gap between resource-rich and resource-poor organisations.
- b) **Data Privacy and Security Concerns:** AI technology relies heavily on extensive patient and clinical data to operate effectively. However, this reliance raises significant concerns regarding data privacy, security, and confidentiality. There is a risk of unauthorised access to patient data, which can lead to legal and ethical issues. Ensuring data security and compliance with data protection laws while using AI technology in the pharmaceutical industry presents a considerable challenge.
- c) **Ethical Issues:** The integration of AI technology in the pharmaceutical industry presents several ethical concerns, including bias, a lack of transparency in decision-making and unclear accountability in the event of errors. For example, if AI systems are trained on biased or incomplete data, they are likely to produce biased or inaccurate results. Furthermore, both patients and medical professionals may struggle to trust the outcomes generated by AI if the decision-making process is not transparent.
- d) **Implementation Barriers:** The implementation of AI technology in the pharmaceutical industry demands a strong infrastructure, skilled personnel and effective data governance. Unfortunately, many small pharmaceutical companies and medical facilities lack the necessary resources and expertise to successfully adopt AI technology.

This gap may hinder the integration of AI in the pharmaceutical industry, particularly in developing countries.

- e) **Unemployment:** The adoption of AI technology in the pharmaceutical industry has the potential to lead to unemployment within the sector. For example, AI can automate tasks such as data analysis, quality control, and administrative work, which may reduce the demand for human labour. This shift could result in unwanted job losses, a decline in traditional skills, and a decrease in creativity among human professionals if there is an overreliance on AI technology.

4. CONCLUSION:

Artificial intelligence (AI) is revolutionizing the pharmaceutical sector by enhancing the entire drug lifecycle through data-driven methodologies. This review highlights that AI accelerates drug discovery, improves clinical trial design, and optimises manufacturing and quality assurance. Techniques like machine learning and deep learning allow for rapid analysis of complex biological and clinical data, resulting in shorter development timelines and reduced costs while increasing the likelihood of positive patient outcomes. AI also plays a vital role in developing novel drug delivery systems, personalised medicine, cancer imaging, and antiviral drug discovery, including anti-dengue agents. However, challenges such as data privacy, ethical concerns, high implementation costs, and regulatory issues persist. To address these, it is crucial to create transparent algorithms, establish strong data governance, and foster collaboration among pharmaceutical scientists, healthcare professionals, and regulatory agencies. Ultimately, AI should be viewed as a supportive tool for practitioners. By combining AI with professional expertise, the pharmaceutical field can enhance decision-making, improve care quality, and enable quicker, personalised treatment solutions globally.

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