

# ARTIFICIAL INTELLIGENCE IN CLINICAL PHARMACY: PRESENT USES AND POTENTIAL DEVELOPMENTS

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## Abstract

Artificial Intelligence (AI) is rapidly transforming clinical pharmacy by enhancing the accuracy, efficiency, and personalization of healthcare delivery. This review presents an overview of core AI concepts, including machine learning and deep learning, along with key data sources such as electronic health records, pharmacovigilance systems, and genomic databases that enable AI-driven applications. It discusses current applications in clinical pharmacy, including clinical decision support systems, medication therapy management, adverse drug reaction detection, drug–drug interaction identification, personalized medicine, and dose optimization. The role of AI-enabled tools such as EHR-integrated systems, chatbots, predictive analytics platforms, and mobile health applications is also highlighted. Furthermore, the review examines the major benefits of AI, including improved patient safety, reduced medication errors, enhanced clinical decision-making, and increased operational efficiency. However, challenges such as data privacy and security concerns, algorithmic bias, lack of transparency, limited clinical validation, and integration barriers are critically addressed. Finally, future perspectives focusing on precision pharmacy, integration with omics technologies, real-time patient monitoring, and the development of automated pharmacy systems are discussed. Overall, AI holds significant potential to revolutionize clinical pharmacy practice by enabling data-driven, patient-centered care, although addressing existing limitations is essential for its successful and ethical implementation.

**Keywords:** *Artificial Intelligence, Clinical Pharmacy, Machine Learning, Deep Learning, Clinical Decision Support Systems, Personalized Medicine*

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## **1. INTRODUCTION**

Artificial intelligence (AI) is becoming a disruptive force in healthcare due to advancements in machine learning techniques, computing capacity, and the availability of large-scale health data. Artificial intelligence has made it possible for healthcare systems to handle and analyze complex datasets, identify hidden patterns, and support clinical decision-making more successfully and precisely. AI has the potential to dramatically change clinical pharmacy medication management by improving drug safety, simplifying therapeutic regimens, and enabling customized treatment plans. The increasing use of digital health technology, including electronic health records and health information systems, has hastened the incorporation of AI into pharmacy practice (He et al., 2019; Rajkomar et al., 2019).

Clinical pharmacy focuses on ensuring the safe, effective, and rational use of medications, requiring continuous evaluation of patient-specific factors, drug interactions, and therapeutic outcomes. However, the growing complexity of pharmacotherapy, coupled with the expanding volume of biomedical data, presents significant challenges for healthcare professionals. AI addresses these challenges by enabling predictive analytics, automating routine processes, and supporting evidence-based clinical decisions. Applications such as intelligent prescribing systems, adverse drug reaction detection, and pharmacogenomics-driven therapy are reshaping the traditional role of pharmacists, allowing them to transition from dispensers to integral members of patient-centered care teams (Schork, 2015; Chen et al., 2017).

Furthermore, by enabling early identification of medication-related issues and ongoing patient health monitoring, AI is supporting a paradigm shift in healthcare from reactive to proactive. This change is especially crucial for managing chronic illnesses, when long-term medication compliance and customized treatment are essential for getting the best results. The application of AI in clinical pharmacy is fraught with difficulties despite its encouraging promise, including issues with data privacy, algorithmic bias, lack of standardization, and integration obstacles within current healthcare systems. Therefore, for AI to be effectively adopted, a thorough understanding of its applications, advantages, and limitations is necessary. The goal of this study is to present a thorough examination of AI's position in clinical pharmacy, emphasizing both its present uses and its potential to enhance healthcare delivery in the future.

## **2. Artificial Intelligence in Healthcare: Core Concepts**

### **2.1 Definition of Artificial Intelligence, Machine Learning, and Deep Learning**

Because it allows computational systems to mimic human intelligence and facilitate intricate clinical decision-making, artificial intelligence (AI) has emerged as a key component of contemporary healthcare. The exponential growth of medical data, improvements in processing power, and the demand for better patient care in terms of efficiency, accuracy, and personalization are driving the integration of AI into healthcare systems. By analyzing extensive clinical datasets, AI in clinical pharmacy improves pharmacovigilance, optimizes therapeutic outcomes, and facilitates drug management (Topol, 2019; Jiang et al., 2017). These features establish AI as a crucial facilitator of evidence-based pharmacy practice and precision medicine.

### **2.1 Definition of Artificial Intelligence, Machine Learning, and Deep Learning**

The creation of computer systems that are able to carry out tasks that normally require human intelligence, such as learning, reasoning, problem-solving, perception, and language comprehension, is known as artificial intelligence (AI). AI systems in the healthcare industry evaluate both structured and unstructured data from a variety of sources, such as imaging systems, laboratory reports, and electronic health records (EHRs), to help physicians diagnose patients and make treatment decisions (Russell & Norvig, 2021; Davenport & Kalakota, 2019). The most significant subfields of artificial intelligence (AI) are machine learning and deep learning. AI comprises a wide range of technologies.

A branch of artificial intelligence called machine learning (ML) allows systems to learn from data and enhance their predictive capabilities without the need for explicit programming. ML algorithms find patterns in datasets and utilize these patterns to provide classifications or predictions. ML is frequently used in clinical pharmacy to manage medication therapy, identify drug-drug interactions, predict adverse drug reactions, and optimize dose schedules (Obermeyer & Emanuel, 2016; Beam & Kohane, 2018). Supervised learning, unsupervised learning, and reinforcement learning are the three main categories of machine learning techniques, each of which has specific therapeutic uses.

Multilayered artificial neural networks are used in Deep Learning (DL), a subfield of machine learning, to handle complicated, high-dimensional input. Clinical narratives, radiological pictures, and genomic sequences are examples of unstructured healthcare data that these algorithms are very good at assessing. Because deep learning can automatically extract hierarchical characteristics from raw data, it has shown improved performance in fields including disease diagnosis, medication development, and individualized treatment planning (LeCun et al., 2015; Esteva et al., 2017). DL approaches are being used more and

more in clinical pharmacy for real-time clinical decision support, patient risk stratification, and pharmacogenomic predictions.

The technological underpinnings of intelligent healthcare systems are formed by AI, ML, and DL working together to improve clinical pharmacy practice's accuracy, efficiency, and personalization. It is anticipated that their ongoing development will enhance patient outcomes and further change the way healthcare is delivered.

## **2.2 Data Sources Used in Clinical AI Systems**

To produce precise forecasts and assist in clinical decision-making, clinical artificial intelligence (AI) systems rely on a variety of large-scale datasets. Electronic Health Records (EHRs), which offer extensive patient information such as demographics, diagnosis, medication history, laboratory findings, and clinical notes, are among the most significant data sources. Machine learning models can use these longitudinal datasets to find trends in treatment response, adverse medication responses, and disease progression. Furthermore, pharmacovigilance databases and clinical trial data provide high-quality knowledge on drug safety and efficacy, enabling AI systems to improve medication therapy management and identify safety signals (Rajkomar et al., 2018; Harpaz et al., 2012).

Medical imaging data and omics data, including proteomics, metabolomics, and genomes, constitute another important area. While omics data enable the development of personalized medical techniques by finding genetic factors impacting medication metabolism and therapeutic response, deep learning algorithms may extract complicated features from imaging datasets to aid in diagnosis and therapy planning. For pharmacogenomic applications and customized dose plans, these data sources are very helpful in clinical pharmacy (Esteva et al., 2017; Hasin et al., 2017).

Additionally, real-world data from healthcare administrative or claims databases, wearable technology, and mobile health (mHealth) apps offer ongoing, population-level insights about patient health, medication compliance, and healthcare utilization. Predictive analytics is improved and proactive therapeutic treatments are supported by the integration of various diverse data sources. To fully exploit the potential of AI in clinical pharmacy practice, however, issues like data heterogeneity, interoperability, and privacy concerns must be resolved (Beam & Kohane, 2018; Davenport & Kalakota, 2019).

## **2.3 Evolution of AI in Medical and Pharmacy Practice**

Beginning with early rule-based systems in the middle of the 20th century, artificial intelligence (AI) in medical and pharmaceutical practice has undergone numerous revolutionary stages. Symbolic reasoning and expert systems, like MYCIN, which employed

preset rules to help diagnose infectious infections and suggest antibiotic medication, were the main focus of early AI applications in healthcare. Despite demonstrating the potential of AI in clinical decision-making, these systems' limited adaptability and reliance on static knowledge bases prevented their widespread use (Shortliffe, 1976; Jiang et al., 2017). Computerized drug information systems and simple clinical decision support tools were the main benefits for pharmacy practice during this time.

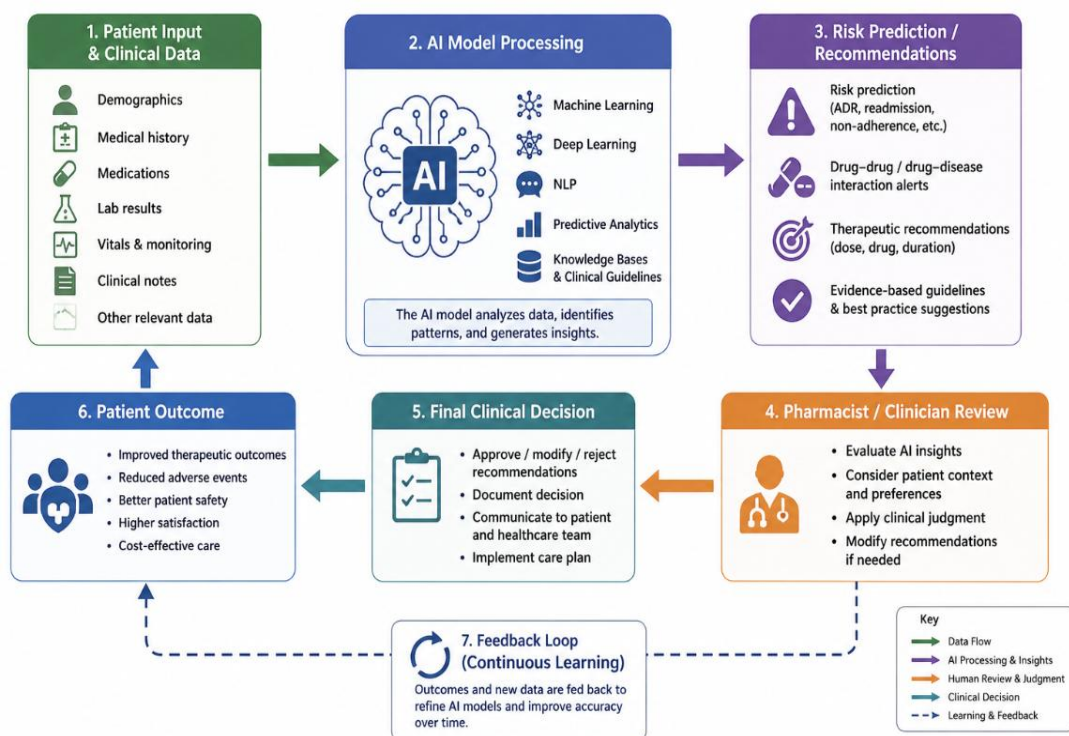
A major movement toward data-driven healthcare was signaled by the following development of machine learning (ML) techniques in the late 20th and early 21st centuries. AI systems are now able to learn from real-world clinical data to enhance diagnostic accuracy, forecast patient outcomes, and optimize drug regimens thanks to the growing availability of electronic health records (EHRs) and massive biological datasets. ML improved patient safety and therapeutic efficacy in clinical pharmacy by enabling improvements in pharmaceutical treatment management, adverse drug response detection, and drug–drug interaction screening (Obermeyer & Emanuel, 2016; Beam & Kohane, 2018). AI applications in healthcare have been significantly transformed in more recent times by the development of deep learning and other computational techniques. Precision medicine and customized medication are made possible by the ability of contemporary AI systems to handle complicated and unstructured data, such as genomic data, clinical narratives, and medical imaging. AI is increasingly included into real-time clinical decision support systems, pharmacovigilance platforms, and electronic prescription systems in pharmacy practice. Furthermore, pharmacists' roles are changing from being traditional dispensers to data-driven clinical decision-makers due to advances like virtual assistants, predictive analytics, and AI-driven drug development platforms (Topol, 2019; Davenport & Kalakota, 2019). This continuous development demonstrates the growing reach and revolutionary influence of AI in contemporary clinical pharmacy practice and healthcare.

**Table 1: Overview of AI Techniques and Their Applications in Clinical Pharmacy**

<b>AI Technique</b>	<b>Description</b>	<b>Clinical Pharmacy Application</b>
Machine Learning	Data-driven predictive modeling	ADR prediction, adherence monitoring
Deep Learning	Neural network-based analysis	Image analysis, pharmacogenomics
Natural Language Processing (NLP)	Text data analysis	Clinical notes, pharmacovigilance
Expert Systems	Rule-based decision systems	CDSS, prescription validation
Reinforcement Learning	Learning via feedback	Dose optimization, treatment planning

### 3. Current Applications of AI in Clinical Pharmacy

By facilitating more accurate, effective, and patient-centered care, artificial intelligence (AI) has quickly increased its position in clinical pharmacy. To help pharmacists optimize pharmaceutical therapy, modern AI systems make use of sophisticated computer models, real-time patient monitoring, and extensive clinical information. Predictive analytics, risk assessment, and customized treatment planning are some of the uses that go beyond conventional dispensing duties. AI is becoming essential to raising pharmaceutical safety, lowering clinical practice variability, and improving overall healthcare outcomes as healthcare systems embrace digital infrastructures more and more (Bates et al., 2018; Yu et al., 2018).



**Figure 1: AI-Driven Clinical Decision-Making Model**

#### 3.1 Clinical Decision Support Systems (CDSS)

AI-powered clinical decision support systems (CDSS) are crucial instruments in contemporary clinical pharmacy practice. These systems give evidence-based suggestions at the point of care by combining clinical guidelines, medical expertise, and patient-specific data. CDSS helps doctors and pharmacists choose the best treatments and reduce errors by evaluating factors like diagnosis, lab results, and drug history. These systems can continuously increase their forecast accuracy and adjust to changing clinical evidence because to the integration of machine learning (Kawamoto et al., 2005).

Furthermore, natural language processing is used by AI-enhanced CDSS to derive valuable insights from unstructured clinical data, such as physician notes and discharge summaries. This feature guarantees that important patient data is not missed and enhances the thoroughness of clinical evaluations. Additionally, CDSS is essential for managing chronic illnesses, antimicrobial stewardship, and adhering to guidelines, all of which support standardized and superior care (Sutton et al., 2020).

### **3.2 Medication Therapy Management and Prescription Screening**

By enabling automated and intelligent prescription review procedures, artificial intelligence (AI) has greatly improved pharmaceutical therapy management (MTM). In order to detect drug-related issues including contraindications, therapeutic duplication, and improper drug selection, these systems examine thorough patient profiles that include comorbidities, laboratory results, and concurrent drugs. This enables pharmacists to maximize treatment results by intervening early (Khezri et al., 2022).

Additionally, by lowering manual labor and human error, AI-driven prescription screening systems increase productivity. Additionally, sophisticated models can identify those who are at risk of drug non-compliance and forecast patient adherence tendencies. In the end, this improves long-term treatment success and lowers healthcare costs by enabling focused interventions like counseling and follow-up (Cresswell et al., 2017).

### **3.3 Adverse Drug Reaction Detection and Pharmacovigilance**

AI has transformed pharmacovigilance by making it possible to identify adverse drug reactions (ADRs) quickly and accurately. Conventional ADR detection techniques frequently depend on spontaneous reporting, which may be constrained by delayed signal identification and underreporting. Large amounts of organized and unstructured data from internet sources, clinical narratives, and electronic health records can be analyzed by AI techniques, especially machine learning and natural language processing, to find possible safety signs (Sarker et al., 2015).

AI also makes it easier to monitor drug safety in real-time across a variety of patient demographics, which enables the early identification of uncommon or unexpected side effects. These systems' capacity to identify new threats is enhanced by their ongoing learning from fresh data. Consequently, AI-driven pharmacovigilance improves regulatory decision-making and medication safety surveillance, which eventually leads to better patient outcomes (Coloma et al., 2013).

### **3.4 Drug–Drug Interaction Identification Systems**

Drug–drug interactions (DDIs) are a major concern in clinical pharmacy, and AI has significantly improved their identification and management. Traditional rule-based systems often generate excessive alerts, many of which may not be clinically relevant, leading to alert fatigue among healthcare providers. AI-based systems address this limitation by prioritizing interactions based on clinical significance and patient-specific factors (Duke et al., 2013).

Large pharmacological datasets can also be analyzed by machine learning models to find hitherto unidentified interactions and forecast their possible effects. These systems give individualized risk evaluations by taking into account characteristics including patient age, organ function, and genetic factors. This improves pharmacotherapy's efficacy and safety while increasing clinical settings' workflow efficiency (Vilar et al., 2012).

### **3.5 Personalized Medicine and Pharmacogenomics**

By combining genomic, clinical, and environmental data to customize medication therapy, AI has revolutionized the field of personalized medicine. Pharmacogenomics allows medical professionals to choose the best drug for each patient by using AI algorithms to examine genetic differences that affect drug metabolism, efficacy, and toxicity (Relling & Evans, 2015).

Furthermore, AI advances precision medicine by aiding in the identification of new biomarkers and therapeutic targets. When it comes to treating complicated diseases like cancer, heart disease, and mental illnesses, where treatment outcomes are greatly impacted by individual variability, these technologies are very helpful. AI improves clinical pharmacy interventions' efficacy and safety by facilitating personalized treatment (Johnson et al., 2021).

### **3.6 Dose Optimization and Therapeutic Drug Monitoring**

The accuracy and efficacy of pharmacotherapy have increased thanks to AI-based methods for dose adjustment and therapeutic drug monitoring (TDM). These algorithms predict patient-specific drug reactions and provide the best dosage schedules using machine learning models and pharmacokinetic/pharmacodynamic data. For medications with narrow therapeutic indices, where slight dose variations might result in toxicity or therapeutic failure, this is especially crucial (Keizer et al., 2018).

Furthermore, real-time monitoring and dose modifications based on patient response and evolving clinical situations are made possible by AI-enabled TDM systems. Over time, these systems improve their predicting powers by continuously learning from patient data. Consequently, AI improves customized dose plans, lessens side effects, and improves therapeutic results (Vinks et al., 2019).

### **Table 2: Current Applications of AI in Clinical Pharmacy**

Application Area	AI Role	Benefits
CDSS	Provides clinical recommendations	Improves decision accuracy
Medication Therapy Management	Detects drug-related problems	Enhances therapy outcomes
Pharmacovigilance	Detects ADRs	Improves drug safety
Drug-Drug Interaction Systems	Identifies interactions	Prevents adverse events
Personalized Medicine	Tailors therapy	Improves efficacy
Therapeutic Drug Monitoring	Optimizes dosing	Reduces toxicity

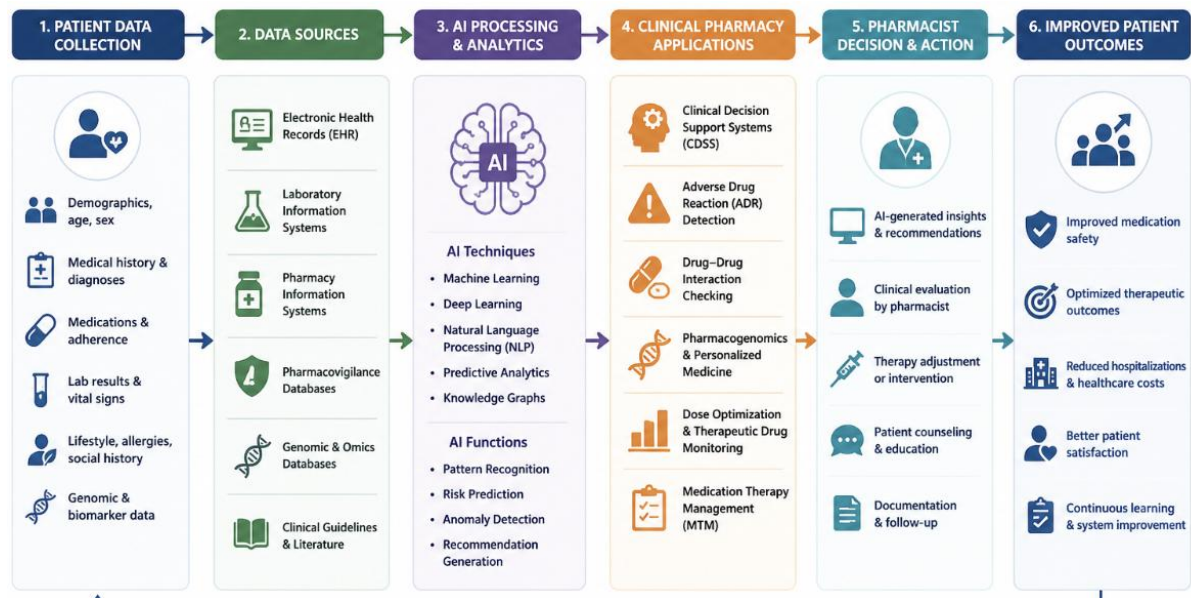


Figure 2: Workflow of AI in Clinical Pharmacy Practice

#### 4. AI-Enabled Tools in Pharmacy Practice

Advanced technologies that promote evidence-based decision-making, increase clinical efficiency, and improve patient involvement have been developed as a result of the incorporation of Artificial Intelligence (AI) into pharmacy practice. Pharmacists may now access real-time information, automate repetitive procedures, and provide more individualized treatment thanks to the increasing integration of AI-enabled technology into healthcare systems. These solutions can improve pharmaceutical safety, increase therapeutic outcomes, and streamline pharmacy workflows by utilizing big datasets, machine learning algorithms, and natural language processing (Bini, 2018; Reddy et al., 2019).

Furthermore, by facilitating smooth communication between healthcare practitioners and enhancing patient information access, AI-enabled systems promote interdisciplinary collaboration. These technologies are transforming pharmaceutical care delivery and facilitating the shift to digital and precision healthcare systems in both hospital settings and community pharmacies.

##### 4.1 Electronic Health Record (EHR)-Integrated AI Systems

One of the most important instruments in clinical pharmacy practice is AI-integrated Electronic Health Record (EHR) systems. These technologies give real-time clinical insights and decision support by combining AI algorithms with patient data. EHR-integrated AI systems help pharmacists detect possible medication errors, suggest suitable therapy, and track treatment results by evaluating patient history, test findings, and medication profiles (Rajkomar et al., 2018).

Additionally, by automating paperwork, identifying abnormal results, and producing clinical warnings, these systems improve workflow efficiency. Proactive interventions are made possible by the ability of advanced AI models integrated into EHRs to forecast patient risks, like as adverse medication events or hospital readmissions. AI is an essential part of contemporary clinical pharmacy practice since it facilitates comprehensive and coordinated patient care when integrated into EHRs (Jensen et al., 2012).

#### **4.2 Chatbots and Virtual Pharmacy Assistants**

AI-powered chatbots and virtual pharmacy assistants are being utilized more frequently to increase patient interaction and offer easily accessible medical information. Natural language processing is used by these technologies to communicate with patients, respond to questions about medications, give dose directions, and remind patients to take their medications as prescribed. They are especially helpful in the management of chronic illnesses, where ongoing patient care is crucial (Bibault et al., 2019).

AI-powered chatbots can also help pharmacists by answering common questions, which lessens their workload and frees them up to concentrate on more difficult clinical duties. Additionally, patient-reported data, such as symptoms and adverse drug reactions, can be gathered by these systems and utilized for clinical decision-making and monitoring. Chatbots are anticipated to significantly improve patient-centered pharmacy services as conversational AI develops.

#### **4.3 Predictive Analytics Platforms**

Predictive analytics platforms are potent artificial intelligence tools that estimate clinical outcomes and facilitate proactive healthcare treatments by utilizing both historical and current data. These platforms are used in clinical pharmacy to forecast patient risks such as adverse drug responses, prescription non-adherence, and hospital readmissions. Pharmacists can enhance therapeutic outcomes by identifying high-risk patients and implementing tailored interventions (Obermeyer & Emanuel, 2016).

Additionally, predictive analytics supports population health management by analyzing trends across large patient groups. Healthcare systems are able to optimize resource

allocation, enhance drug utilization, and save healthcare expenditures thanks to these findings. Predictive analytics improves decision-making in pharmacy practice and helps to offer healthcare in a more effective and efficient manner (Shickel et al., 2018).

#### **4.4 Mobile Health (mHealth) Applications**

One fast expanding class of AI-enabled technologies in pharmacy practice is mobile health (mHealth) applications. Patients can monitor their health, manage medication adherence, and obtain individualized health advice with these programs, which are available on smartphones and wearable devices. AI systems evaluate user data to deliver customized insights that enhance patient involvement and self-care (Free et al., 2013).

mHealth apps in clinical pharmacy promote communication between patients and healthcare providers and enable remote patient monitoring. These technologies can be used by pharmacists to monitor patient progress, spot possible problems, and offer prompt remedies. Additionally, mHealth platforms help gather data for pharmacovigilance and clinical research. It is anticipated that mHealth applications would become more crucial in providing patient-centered and easily accessible pharmaceutical treatment as digital health technologies advance.

### **5. Benefits of Artificial Intelligence in Clinical Pharmacy**

By improving the effectiveness, safety, and quality of healthcare delivery, artificial intelligence (AI) has many advantages for clinical pharmacy. Pharmacists can make better decisions, lower medication-related hazards, and maximize therapeutic results by integrating AI technologies. AI facilitates the transition from reactive to proactive healthcare by utilizing sizable datasets and sophisticated analysis tools, enabling early detection of possible problems and prompt solutions (Makady et al., 2017; Aung et al., 2021).

**Additionally, AI helps healthcare organizations optimize workflow and make better use of their resources. Routine chores are lessened by automated procedures, freeing up pharmacists to concentrate on patient-centered care. These developments boost the general effectiveness and sustainability of healthcare delivery systems in addition to improving clinical results.**

#### **5.1 Improvement in Patient Safety and Clinical Outcomes**

One of the most significant benefits of AI in clinical pharmacy is the enhancement of patient safety and clinical outcomes. AI systems can analyze vast amounts of patient data to identify potential risks, such as adverse drug reactions, contraindications, and inappropriate

medication use. By providing real-time alerts and evidence-based recommendations, AI helps prevent medication-related harm and ensures safer therapeutic interventions (Classen et al., 2011).

In addition, AI supports personalized treatment strategies by considering patient-specific factors such as genetics, comorbidities, and lifestyle. This individualized approach improves the effectiveness of therapies and reduces the likelihood of treatment failure. AI-driven monitoring systems also enable continuous assessment of patient response, allowing timely adjustments to therapy and improved overall health outcomes (Topol, 2019).

## **5.2 Reduction in Medication Errors**

AI is essential to reducing medication errors, which are a significant problem in healthcare. By examining patient data and prescriptions for discrepancies, AI-powered systems can identify problems in prescription, dispensing, and administration. By alerting users to problems including wrong dosages, drug interactions, and redundant therapy, these systems lower the possibility of dangerous mistakes (Assiri et al., 2018).

Additionally, automating standard pharmacy procedures like medication reconciliation and prescription validation lowers human error and increases accuracy. By guaranteeing that accurate and current patient data is easily accessible, AI technologies can improve communication between healthcare providers. This leads to better patient outcomes and safer drug practices (Keers et al., 2013).

## **5.3 Enhanced Clinical Decision-Making**

AI greatly improves healthcare decision-making by offering evidence-based suggestions and data-driven insights. Complex clinical data can be analyzed by sophisticated algorithms to find patterns that medical professionals might miss. This makes it possible for pharmacists to choose, dose, and monitor medications more precisely and quickly (Sendak et al., 2020).

AI systems also aid in decision-making by combining patient-specific data, research findings, and therapeutic recommendations onto a single platform. This encourages uniform care and lessens clinical practice variability. AI enables pharmacists to provide excellent, patient-centered care with more assurance and accuracy by enhancing rather than replacing human expertise (Jiang et al., 2017).

## **6. Challenges and Limitations**

Artificial Intelligence (AI) has the potential to revolutionize clinical pharmacy, but a number of obstacles and restrictions prevent its general acceptance and successful application. Data quality, ethical issues, regulatory ambiguities, and technology limitations are the main causes of these difficulties. The performance and dependability of AI systems can be greatly impacted by problems with data integrity, interoperability, or accessibility since these systems rely largely on big and heterogeneous datasets. Furthermore, incorporating AI into clinical workflows calls for significant organizational support, infrastructure, and training—all of which might not be easily accessible in all healthcare settings (Kelly et al., 2019; Panch et al., 2019).

Furthermore, issues with trust, responsibility, and the moral use of AI technology continue to be crucial. Without a comprehensive grasp of the decision-making process, healthcare personnel can be reluctant to rely on AI-driven advice. To guarantee the safe, efficient, and moral application of AI in clinical pharmacy practice, these issues must be resolved.

### **6.1 Data Privacy and Security Issues**

Ensuring data confidentiality and privacy is one of the main obstacles to integrating AI in clinical pharmacy. Sensitive patient data, such as medical history, genetic information, and prescription records, must be accessible to AI systems. Concerns around confidentiality, illegal access, and possible data breaches are raised by the use and sharing of such data. Although it can be difficult and resource-intensive, adherence to data protection requirements, such as those pertaining to health information privacy, is crucial (Rieke et al., 2020).

Additional dangers are introduced by the growing usage of data-sharing networks and cloud-based systems. To safeguard patient data, strong encryption, safe data storage, and restricted access methods are essential. If these issues are not resolved, trust in AI systems may be damaged, and their use in clinical pharmacy settings may be restricted (Price & Cohen, 2019).

### **6.2 Algorithm Bias and Lack of Transparency**

Another major drawback of AI systems in healthcare is algorithmic bias. Unrepresentative or unbalanced training datasets can give birth to bias, which can result in erroneous predictions and uneven healthcare results for various patient populations. This could lead to unfair treatment choices or improper drug recommendations in clinical pharmacy, especially for underrepresented populations (Obermeyer et al., 2019).

Furthermore, a lot of AI models—particularly deep learning systems—act as "black boxes," making it challenging to comprehend how particular judgments are made. The adoption of AI tools in practice may be hampered by this lack of openness, which can also erode clinician trust. To solve these issues and guarantee responsible use of AI technology, efforts to create explainable AI (XAI) and enhance model interpretability are essential (Samek et al., 2017).

### **6.3 Limited Clinical Validation and Standardization**

AI systems' inadequate clinical validation continues to be a significant obstacle to their general implementation. Although many AI models are created and evaluated in controlled research settings, their effectiveness might not translate well to actual clinical situations. The validity and applicability of AI-driven suggestions may be impacted by differences in patient groups, medical procedures, and data quality (Liu et al., 2019).

Furthermore, inconsistent utilization of AI systems results from the absence of established rules for their development, validation, and implementation. It is difficult to guarantee the safety, effectiveness, and repeatability of AI applications in clinical pharmacy in the absence of strong regulatory frameworks and established evaluation techniques. Building trust in these technologies requires the establishment of precise standards and validation procedures (Benjamens et al., 2020).

### **6.4 Integration Barriers in Healthcare Systems**

There are many organizational and technical obstacles to overcome when integrating AI technologies into current healthcare infrastructures. Advanced AI technologies could not be compatible with the older platforms used by many healthcare institutions. The efficacy of AI technologies might be restricted and smooth data flow impeded by interoperability problems between various software systems (Kellermann & Jones, 2013).

AI implementation also necessitates large infrastructure, training, and maintenance investments. To properly employ AI tools and evaluate their results, healthcare personnel must receive sufficient training. Adoption may also be hampered by resistance to change, a lack of technical know-how, and worries about disrupting workflow. To successfully integrate AI into clinical pharmacy practice, healthcare organizations, legislators, and technology developers must work together to address these obstacles (He et al., 2019).

## **7. Future Perspectives**

The future of Artificial Intelligence (AI) in clinical pharmacy is poised to bring transformative advancements that will redefine pharmaceutical care and healthcare delivery. As AI technologies continue to evolve, their integration with emerging digital health innovations is expected to enhance precision, efficiency, and accessibility of pharmacy

services. Future developments will likely focus on real-time data utilization, personalized therapeutics, and automation of complex clinical processes. These advancements will not only improve patient outcomes but also expand the role of pharmacists as key contributors to interdisciplinary healthcare teams (Topol, 2019; Yu et al., 2018).

Moreover, the convergence of AI with genomics, wearable technologies, and big data analytics will enable a shift toward predictive and preventive healthcare. This will facilitate early disease detection, individualized therapy, and continuous patient monitoring. As healthcare systems adapt to these innovations, AI is expected to become an integral component of both hospital and community pharmacy practice.

### **7.1 AI in Precision and Personalized Pharmacy**

AI is expected to play a central role in advancing precision and personalized pharmacy by tailoring drug therapy to individual patient characteristics. By integrating clinical, genetic, and environmental data, AI systems can predict drug response, optimize medication selection, and minimize adverse effects. This approach moves beyond traditional population-based treatment strategies toward individualized care, improving therapeutic efficacy and patient satisfaction (Collins & Varmus, 2015).

In the future, AI-driven platforms will enable real-time personalization of treatment regimens based on continuously updated patient data. Pharmacists will increasingly rely on AI tools to make informed decisions regarding drug selection and dosing, thereby enhancing the effectiveness and safety of pharmacotherapy.

### **7.2 Integration with Genomics and Omics Technologies**

The integration of AI with genomics and other omics technologies (such as proteomics and metabolomics) represents a major advancement in clinical pharmacy. AI algorithms can analyze complex biological datasets to identify genetic variations and molecular pathways that influence drug response. This integration will enable the development of highly targeted therapies and support the implementation of pharmacogenomics in routine clinical practice (Hasin et al., 2017).

Additionally, AI will facilitate the discovery of novel biomarkers and therapeutic targets, accelerating drug development and improving treatment outcomes. As omics technologies become more accessible, their combination with AI will significantly enhance personalized medicine and precision pharmacy.

### **7.3 Real-Time Clinical Monitoring Systems**

Future AI systems will enable continuous, real-time monitoring of patients through integration with wearable devices, sensors, and mobile health technologies. These systems will collect and analyze physiological data such as heart rate, blood pressure, and medication adherence, allowing early detection of clinical deterioration or adverse drug events (Steinhubl et al., 2015).

Such real-time monitoring will empower pharmacists to intervene promptly and adjust therapy as needed. This proactive approach will improve patient safety, reduce hospitalizations, and enhance chronic disease management. AI-driven monitoring systems will also support remote healthcare delivery, making pharmacy services more accessible.

### **7.4 Expansion in Community and Hospital Pharmacy Practice**

AI is expected to expand its applications across both community and hospital pharmacy settings. In community pharmacies, AI-powered tools such as chatbots, mobile applications, and automated dispensing systems will enhance patient engagement and improve medication adherence. Pharmacists will be able to provide more personalized counseling and remote support, increasing the accessibility of healthcare services (Bates et al., 2018).

In hospital settings, AI will support advanced clinical functions such as therapeutic drug monitoring, antimicrobial stewardship, and critical care management. The integration of AI into pharmacy workflows will improve efficiency, reduce medication errors, and enhance interdisciplinary collaboration. This expansion will redefine the role of pharmacists as technology-enabled healthcare providers.

### **7.5 Fully Automated Clinical Pharmacy Ecosystem**

The development of a fully automated clinical pharmacy ecosystem represents a long-term vision for AI integration. In such a system, AI technologies will automate processes including prescription validation, drug dispensing, medication monitoring, and clinical decision support. Robotic systems, combined with AI algorithms, will ensure high accuracy and efficiency in medication management (Davenport & Kalakota, 2019).

Furthermore, interconnected AI platforms will enable seamless data exchange across healthcare systems, facilitating coordinated and patient-centered care. While human oversight will remain essential, automation will allow pharmacists to focus on complex clinical decision-making and patient care. This evolution toward a fully automated ecosystem has the potential to significantly enhance the quality, safety, and efficiency of clinical pharmacy practice

## **8. Conclusion**

Artificial Intelligence (AI) is significantly transforming clinical pharmacy by enhancing the accuracy, efficiency, and safety of medication management. Its applications across clinical decision support, pharmacovigilance, personalized medicine, and therapeutic drug monitoring have demonstrated strong potential in improving patient outcomes and optimizing therapeutic strategies. By enabling data-driven and evidence-based decision-making, AI supports pharmacists in delivering high-quality, patient-centered care while reducing the likelihood of medication-related errors.

However, the widespread implementation of AI in clinical pharmacy is not without challenges. Issues such as data privacy and security, algorithmic bias, limited clinical validation, and integration barriers must be carefully addressed to ensure safe and effective use. Overcoming these challenges will require the development of robust regulatory frameworks, standardization of AI systems, and continuous education and training of healthcare professionals.

Looking forward, AI is expected to play an increasingly vital role in shaping the future of clinical pharmacy. Advances in precision medicine, real-time patient monitoring, and automated healthcare systems will further enhance the scope and impact of pharmacy practice. Rather than replacing pharmacists, AI will augment their capabilities, allowing them to focus more on clinical and patient-oriented roles. Ultimately, the successful integration of AI into clinical pharmacy will contribute to more efficient healthcare systems and improved patient care outcomes.

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## **10. Conflict of Interest**

The authors declare that there is no conflict of interest regarding the publication of this review.

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