International Journal of Advances in Applied Sciences (IJAAS)
Vol. 14, No. 4, December 2025, pp. 1305~1321
ISSN: 2252-8814, DOI: 10.11591/ijaas.v14.i4.pp1305-1321

AI-integrated pharmacy systems: bridging technology, ethics, and patient care

Adi El-Dalahmeh[1], Nevien Nedal[2], Khulood Abu Maria[3], Sara Abu Tarboosh[2]
[1]Department of Cybersecurity, Faculty of Science and Information Technology, Al-Zaytoonah University of Jordan, Amman, Jordan
[2]Faculty of Pharmacy, Al-Zaytoonah University of Jordan, Amman, Jordan
[3]Department of Computer Science, Faculty of Science and Information Technology, Al-Zaytoonah University of Jordan, Amman, Jordan

Article Info

Article history:

Received Jun 23, 2025
Revised Sep 28, 2025
Accepted Nov 04, 2025

Keywords:

Artificial intelligence in pharmacy
Ethical challenges
Medication safety
Personalized medication management
Technology

ABSTRACT

The operation of pharmacy systems undergoes transformation through artificial intelligence (AI), which advances from manual procedures to intelligent adaptive tools. These technologies enhance daily operations through prescription verification, drug interaction alerts, and inventory management while decreasing human mistakes. Through AI, patients gain access to customized medication recommendations, automatic appointment alerts, and virtual support services. The advancement of technology creates multiple new difficulties for healthcare systems. The increasing integration of AI in healthcare creates growing concerns about data privacy alongside algorithmic bias and the requirement for decision-making explanations. This paper evaluates AI systems against conventional pharmacy methods through an assessment of their precision and speed and their impact on patient safety and ethical preparedness. The adoption of AI systems requires strong ethical protections together with defined regulatory frameworks to maintain human clinical decision-making authority in patient care.

This is an open access article under the CC BY-SA license.

Corresponding Author:

Adi El-Dalahmeh
Department of Cyber Security, Al-Zaytoonah University of Jordan
St. 594, Al Zaytoonah University of Jordan, Airport Rd., Amman, Jordan
Email: A.eldalahmeh@zuj.edu.jo

1. INTRODUCTION

The conventional pharmacy system relies largely on manual procedures. This reliance on manual procedures makes the system prone to inefficiency, errors, delays, and suboptimal results, which could endanger patients' lives or hinder the achievement of economic objectives in therapy [1]. This is the current state of affairs. In these traditional distribution systems, which are generally characterized by centralized management, it is impossible to accurately accommodate different patient characteristics or various comorbidities, such as AIDS. That means that medical reasoning must be abandoned and replaced with blessings in mantras [2]. With the integration of artificial intelligence (AI) into pharmacy systems, however, comes a transformational breakthrough that can handle key pharmacy workflows, including prescription interpretation, dosage calculation, drug interactions, release checks, and inventory management [3].

For hospitals and doctors' surgeries to function effectively, they must accept this technological development. However, with AI technologies such as machine learning (ML) and natural language processing (NLP), we can eliminate human error, speed up the delivery of routine services, and offer clinical decision support by providing evidence-based recommendations tailored to individual patient data [4]. It is this change that is fueling the current wave of innovation that began some time ago. In addition to prescription adherence data being continuously generated by smart devices, customers can now access a composite view of their medication history (whether or not they are online) anywhere and anytime, which is democratizing healthcare. This procedure should be a model for future medical history (or personal health statistics) archives a la cybermedicine in all but name [5]. Thus, by analyzing medical histories and real-time data, tools enabled with AI technologies can proactively detect potential drug interactions or adverse medical events in this way, contributing to promoting medication safety [5]. But the application of AI in pharmacy will bring its problems too, like those of data safety, algorithmic bias, transparency, and the unfortunate lack of AI to express human emotion. Furthermore, the potency of AI is always only as satisfactory as the quality of its input data: inconsistencies may render AI's decisions suboptimal [6]. And maintaining such systems as these inevitably requires significant investment and expertise. This poses a barrier to adoption [7].

Therefore, this study will investigate the introduction of an AI-based pharmacy system. To this end, we propose an integrated evaluation framework that reviews not just the increase in activity levels and customization with AI-based pharmacy systems but also the ethical problems in between. Compared with traditional systems, this research will help to distinguish how AI might best consolidate operations, improve the accuracy of medical records, and foster patient care, while at the same time, it lays out a road map to social responsibility associated with pharmacy engagements. Figure 1 illustrates key differences between manual and AI-powered pharmacy systems, highlighting automation, efficiency, and personalization.

The main contribution of the paper is the development of an integrated evaluation framework that considers both operational efficiency and personalization capabilities in AI-based pharmacy systems over a resulting ethical risk map. Many of the studies to date have looked at technical performance separate from ethical concerns. Our approach allows a comprehensive consideration of AI systems in pharmacy that incorporate current and future advances in automation and personalization while being mindful of patient safety, equity, and transparency.

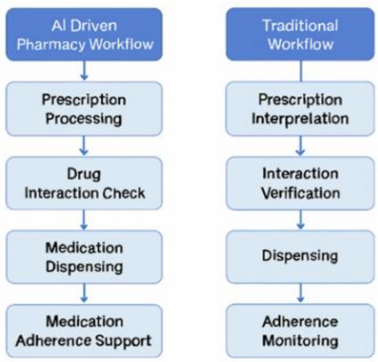


Figure 1. Comparison of traditional vs AI-driven pharmacy workflows

2. LITERATURE REVIEW

The research on AI implementation in pharmacy systems divides into four thematic areas that reflect the core operational, clinical, and ethical dimensions of modern adoption. These themes collectively address how AI enhances workflow efficiency, strengthens decision-making, improves patient safety, and upholds essential ethical standards such as privacy and accountability. Understanding these four thematic areas is crucial for evaluating both the opportunities and challenges associated with integrating AI technologies into pharmacy practice.

2.1. Use of AI for clinical decision support and medication safety

AI has gone from a primitive level of alerting to far more advanced predictive analytics in clinical decision support systems (CDSS). More recently, its role has been associated with the increasing attention to medication safety. Chalasani *et al.* [1] performed a systematic review of AI-based tools for clinical pharmacy services and observed that, even though adoption marketing was directed towards NLP technology, concerning the reduction of prescription and dispensing errors, there was more evidence favoring integrated systems (NLP and clinical ruleset). Expanding on this, Sridhar *et al.* [8] presented the use of ML models for real-time dose validation and drug interaction screening in hospital pharmacy practice and showed that this has led to some reduction in adverse drug events [2]. Additionally, a comparative analysis found that large language models (LLMs) can achieve performance akin to clinical pharmacists in identifying common drug interactions, but it also demonstrated they were unable to cope well with complex patients, accordingly underlining once more the relevance of the human-AI hybrid model [3].

2.2. Artificial intelligence in robotic dispensing and automation

AI is now part of dispensing robots in a way that goes beyond mere automation and allows adaptive and error-free workflows. Stasevych and Zvarych [9] review of emerging robot technologies noted that AI-based vision systems can be used to confirm pill identification, dose accuracy, and the integrity of labels, reducing dispensing errors [4]. This is consistent with trends in practical pharmacy; AI-based inventory management systems based on predictive algorithms are used to predict the demand for drugs and stock adjustment for mitigating either over- or under-stock conditions [5]. These tools increase speed and delegate pharmacists to more complicated clinical work.

2.3. AI for patient-centered pharmacist services

One of the major areas is using AI to provide patient-centric personalized care. Research on medication therapy management indicates that the use of AI has the potential to deliver individualized patient education and adherence support [6]. For long-term and chronic condition management, AI-based software services coupled with wearables are better suited to monitor the health data of patients and deliver personalized interventions. Fahim *et al.* [7] reported AI-based mobile health apps and chatbots that provide 24/7 access to pharmaceutical information, which can result in enhanced accessibility. This context is framed by the digital disruption of pharmacy and emphasizes how such platforms empower patients while transforming the pharmacist's role towards a focus on patient outcomes.

2.4. Explainable artificial intelligence and transparency in healthcare

The necessity of transparency has increased as AI systems become more sophisticated. For patients, it is critical to have a model that is understandable in a clinical setting. Raza and Aziz [10] also claimed that interpretable models become a necessity in decision support systems to be adopted, since black-box algorithms could hinder utilization in high-stakes contexts such as data-driven pharmacotherapy. A meta-analysis on the performance and limitations of LLMs in healthcare applications confirms this, with an emphasis on interpretability [9], [11]. At the same time, the ethical implications are subject to intense scrutiny. A recent paper snapshot showed patient consent, privacy, and algorithmic bias as key concerns for pharmacists, with a need for transparent governance principles [8].

2.5. Ethical and regulatory frameworks

The implementation of AI in pharmacy operations creates ethical problems, according to Hasan *et al.* [2], because it involves obtaining patient consent, protecting data privacy, and preventing algorithmic bias. The evaluation of systems should include FAT metrics, according to policy bodies that recommend their implementation [9]. The research findings are condensed into Table 1, which shows their research approaches together with their practical applications and main research constraints.

Table 1. Summary of reviewed studies

Author(s)	AI application	Dataset/scope	AI method	Key limitation
Ranchon *et al.* [4]	Drug interaction verification, dose accuracy	Systematic review of apps/tools	NLP, rules-based systems	Limited real-time validation
Roosan *et al.* [12]	Medication adherence and therapy management	Simulation and case-based scenarios	ChatGPT and adaptive models	Limited generalizability to clinical trials
Smoke [13]	Explainability in clinical AI systems	Expert commentary	XAI	Theoretical, not tested empirically
Hasan *et al.* [2]	Ethical concerns in AI pharmacy tools	Survey-based cross-sectional study	None (ethical assessment)	Relies on self-reported concerns
Sallam *et al.* [14]	AI tools in pharmacy education	Descriptive analysis of educational use	ChatGPT-3.5 in academic settings	No direct performance benchmarking
Jin *et al.* [11]	Performance of GPT in pharmacy exams	Meta-analysis of exam Performance	GPT-4 exam simulation	Focused on testing, not practice

3. METHODS

In addition to the architectural formulation, this study employs a conceptual evaluation framework to systematically examine how the proposed AI-based pharmacy system performs across clinical, operational, and ethical dimensions. The assessment process integrates evidence from prior empirical studies with theoretical modeling to determine the system's expected impact on patient outcomes, workflow efficiency, and medication-related safety. Furthermore, the method incorporates a multi-criteria comparison between the AI-enabled model and traditional pharmacy practices, ensuring that each component of the architecture is evaluated against validated benchmarks. This structured methodological approach allows for a comprehensive understanding of the potential benefits, limitations, and real-world feasibility of adopting AI within pharmacy environments.

3.1. Study design

The study follows a theoretical and design-science approach. This includes integrating insights from articles and white papers into a proposed AI-based pharmacy system architecture. Subsequently, the performance and effects of this proposed system are analyzed in comparison with traditional pharmacy models using predefined metrics from previous studies.

3.2. The proposed AI-based pharmacy system architecture

The proposed architecture adopts the three layers of a typical ML-based DI framework, yielding ample routes from data ingestion to user interaction.

i) Data layer: this is the first layer, which collects and orchestrates different sources of information. It integrates with:
- Electronic health records (EHRs): to view patient history, diagnoses, and current medications.
- Pharmacy dispensing systems: To provide information on drug history and refill behavior.
- Patient-generated health data (PGHD): wearables (e.g., glucose monitors, smartwatches) and PRO from mobile apps.
- Drug knowledge bases: the latest databases of drug interactions, side effects, and pharmacogenomics.

ii) AI processing and analytics layer: this is the brain of intelligence where data gets converted into information. It hosts several AI modules:
- NLP engine that can interpret free-text prescriptions and patient questions
- ML models (“predictive"): these models are used to model predictive analytics, including risk of adherence and the prediction of adverse events.
- Section 3.3 presents the details of this engine's logic.
- The system reads the pharmacist’s alerts and evidence-based clinical, therapeutic, and pharmacological recommendations.

iii) Application layer: it comes into contact with the end-user.
- Pharmacist dashboard: uses AI-generated alerts, patient risk scores, and workflow optimization tools.
- Patient mobile application: provides customized reminders, information, and a line of communication with the pharmacy.

3.3. Personalization logic

This personalized patient care is established through a feedback loop of dynamic interplay in the AI processing layer. The logic operates as follows:

i) Integration of data: patient-level information from the data layer (e.g., age, weight, genetic markers, and co-morbidities, real-time vitals from wearables) pours into the personalization engine.

ii) Profile creation and risk profiling: ML solutions algorithmically parse this data to form a live profile of patients. This encompasses the risk score of non-adherence, adverse drug reaction, and therapeutic failure.

iii) Intervention selection: given the profile and risk score, the engine selects from a list of customized interventions. For example:
- A patient classed as high-risk for non-adherence can be sent more reminders, and even context-aware ones.
- A patient with a certain genetic marker would automatically fire off an alert to the pharmacist to try another drug instead.

iv) Delivery and tracking: the intervention strategy selected (e.g., tailored reminder, educational message, pharmacy alert) is delivered from the application layer. The system subsequently tracks the level of engagement among patients and updates based on their health data as it analyzes the applicability of intervention.

v) Feedback loop: the results (e.g., medication taken and health metric improved) are also brought back into the system so that ML models can iterate to further refine and improve personalization logic for this individual.

3.4. Evaluation metrics

The AI system is compared with traditional pharmacy systems based on multiple metrics in four domains. The development of these measures was informed by a combination of performance indicators established in the literature review [1], [2], [6]. Table 2 outlines the evaluation metrics used to assess AI-driven pharmacy systems across four domains: operational efficiency, clinical safety, patient outcomes, and ethical governance. These metrics measure improvements in processing speed, medication accuracy, patient adherence, and compliance with privacy and transparency standards.

Table 2. AI in pharmacy system evaluation metrics

Domain	Evaluation metric	Description
Operational efficiency	Prescription processing time	Time from prescription receipt to final verification (in minutes)
Operational efficiency	Inventory turnover ratio	Efficiency of inventory management
Operational efficiency	Pharmacist intervention rate	times of AI recommendations can be corrected.
Clinical safety and accuracy	Medication error rate	Prescriptions with errors (e.g., incorrect drug name, dose, or duration) before and after AI
Clinical safety and accuracy	Drug interaction alert accuracy	Precision in AI-generated drug interaction alerts (true positives/[true positives+false positives])
Clinical safety and accuracy	Adverse drug event reduction	Rate of reported Adverse drug events during a benchmark period (e.g., in total or on average per day)
Patient-centric outcomes	Medication adherence rate	Measured by the proportion of days covered (PDC)
Patient-centric outcomes	Patient satisfaction score	Standardized surveys, like the Net Promoter Score, are the best way to measure such data.
Patient-centric outcomes	Patient empowerment	Surveys of comprehension concerning the function and side effects of medication
Ethical and technical governance	Algorithmic bias audit	The question is whether recommendation accuracy varies across demographic groups such as age, gender, and ethnicity.
Ethical and technical governance	System transparency and explainability	Can the system provide an understandable reason for a recommendation (e.g., using explainable AI-XAI)?
Ethical and technical governance	Data privacy and security compliance	Audit logs and security penetration tests measure compliance with standards like HIPAA/GDPR.

3.5. Data sources and conceptual simulations

As the study was conceptual in nature, actual deployment data were not available. Thus, the assessment relies on an analysis of secondary data from Scopus-indexed peer-reviewed articles and reports from regulatory agencies such as the WHO and the EU commission. A prototypical comparative analysis, based on simulation and ethical evaluation, was established to demonstrate some of the potential functionality and dangers posed by the proposed system as a blueprint for future empirical research.

3.5. Ethical considerations

Ethical considerations were addressed throughout the study, despite the absence of human subjects and the resulting exemption from IRB approval. To ensure responsible system design, the research incorporated principles from published literature on AI transparency, data privacy, and fairness. These ethical guidelines informed both the development of the proposed architecture and the criteria used to evaluate its safety, reliability, and societal impact.

4. NEED FOR AI IN PHARMACY SYSTEM

As the integration of AI into pharmacy systems gains momentum, its implementation must be approached with careful planning and thoughtful consideration [12]. While AI has the potential to transform the field through personalized medication management and ongoing patient care, ensuring its use remains ethical and responsible is vital [10]. To maximize its effectiveness, potential challenges and limitations must be thoroughly examined. Therefore, adopting a well-researched, evidence-driven strategy is critical for the safe and effective incorporation of AI into pharmacy practice.

ChatGPT said, the growing global population stands to benefit greatly from AI-based pharmacy systems, which can help meet the rising demand for healthcare services [9]. By delivering customized medication management and continuous patient support, AI enhances adherence to treatment plans, reducing the frequency of healthcare visits [8]. This not only alleviates pressure on healthcare infrastructures but also improves access to medical care. Furthermore, AI plays a vital role in reducing medication errors and avoiding adverse drug interactions, leading to better patient outcomes and lower overall healthcare expenditures [15]. By streamlining drug management and assisting healthcare professionals, AI contributes to overcoming the challenges brought about by population growth and the increasing need for medical services [16].

Integrating AI into pharmacy systems can generate positive global impacts in multiple ways [17]. To begin with, AI can enhance healthcare accessibility by offering individualized medication management and continuous support, enabling patients to handle their treatments more effectively while minimizing the need for frequent face-to-face consultations—an especially valuable benefit for those living in remote or underserved areas. Moreover, AI can help reduce healthcare expenditures by minimizing medication errors and avoiding adverse drug interactions, thereby lowering hospitalization rates and overall medical costs [18]. By automating repetitive administrative processes, AI also eases the burden on healthcare professionals, enabling them to dedicate more time to complex patient care and improving the overall quality of services. In essence, AI-driven pharmacy systems hold the promise of improving patient outcomes, decreasing healthcare costs, and expanding access to medical services, ultimately fostering a more efficient and equitable global healthcare system.

5. IMPLEMENTATION PROCESS OF AI IN PHARMACY SYSTEM

The evaluation process for assessing AI-administered pharmacy system parameters may involve several structured steps [19], [20]. These steps typically begin with defining measurable indicators related to accuracy, efficiency, safety, and patient outcomes, followed by applying established benchmarks from prior research. Finally, the system's performance is compared against traditional pharmacy workflows to determine the extent of improvement and identify any remaining gaps.

5.1. Defining the parameters

To begin with, it is important to establish a clear framework that specifies the key aspects to be assessed—such as how medications are managed, how patients are monitored and communicated with, how drug interactions and adverse effects are detected, and how EHRs and analytical data are utilized. Setting these benchmarks provides a structured basis for evaluating the performance and effectiveness of AI within pharmaceutical systems. Medication management is a critical domain where AI can enhance adherence, reduce medication errors, and guarantee that patients receive accurate prescriptions promptly. Patient communication is a crucial aspect, since AI may offer round-the-clock access to healthcare assistance, address patient inquiries, and dispatch prescription reminders. Moreover, AI can improve patient monitoring by measuring vital signs and other health metrics, notifying healthcare practitioners of potential difficulties prior to their escalation.

AI significantly contributes to the management of drug interactions and adverse drug responses. By providing real-time pharmaceutical information and notifications, it can assist healthcare providers in identifying and averting detrimental interactions. Furthermore, AI can interface with EHR systems to deliver current patient information, facilitating better-informed healthcare decisions. Utilizing data analytics, AI can discern patterns and trends in patient information, providing insights to enhance overall healthcare outcomes. By delineating these dimensions and assessing AI's influence on each, healthcare professionals can gain a clearer comprehension of its prospective uses in pharmacy and its contribution to enhancing patient care.

5.2. Developing measurement tools

To precisely evaluate AI's efficacy, it is essential to develop instruments for quantifying each parameter, such as surveys, questionnaires, or data-gathering forms. The choice of measurement instruments is contingent upon the particular parameter under investigation. Medication adherence can be monitored via a logging tool where patients document their doses, while the efficacy of patient communication can be evaluated through surveys measuring satisfaction with AI-mediated interactions.

Upon development, these technologies require validation to confirm their precision and dependability. The validation procedure may entail testing a limited cohort of patients or healthcare professionals to identify discrepancies or opportunities for enhancement. Ensuring that these technologies regularly and precisely evaluate their intended parameters enables healthcare professionals to successfully assess AI's effectiveness and enhance its deployment in pharmacy systems.

5.3. Collecting data

Collecting data is a crucial step in assessing the impact of AI within pharmacy systems. Information can be sourced from various channels, such as patients, healthcare practitioners, and EHRs. Patients can offer valuable input regarding their medication adherence and interactions with healthcare systems, whereas healthcare providers can contribute details about drug interactions and adverse effects. Additionally, EHRs provide an extensive repository of patient histories, treatment protocols, and clinical outcomes, serving as an essential foundation for analysis.

After data collection, it must be carefully analyzed to identify trends, correlations, and areas for improvement. This information helps assess AI's effectiveness in enhancing the defined parameters and guides future optimization efforts. Additionally, maintaining data accuracy, completeness, and confidentiality is essential, requiring adherence to data security and ethical protocols.

5.4. Analyzing the data

Following data collection, statistical and ML approaches should be applied to analyze the information and detect meaningful patterns or trends. This process can yield critical insights into patient adherence, potential drug interactions, and adverse drug events. Based on these insights, healthcare providers can formulate individualized treatment plans aimed at minimizing the risk of negative health outcomes.

Furthermore, data analysis can identify deficiencies and prospects for enhancement within the pharmacy system. If adherence rates are low, initiatives like improved patient education or automated reminder systems may be implemented to promote compliance. Through ongoing data analysis, healthcare practitioners can optimize pharmacy operations, resulting in improved patient care and enhanced healthcare efficiency.

5.5. Interpreting the results

The subsequent stage focuses on interpreting the analytical findings to evaluate how effectively AI contributes to medication management, enhances patient outcomes, and lowers healthcare expenses. This step entails examining the correlations between the defined parameters and the influence of AI on each of them. For example, if the analysis shows that AI markedly increases medication adherence, it implies that AI-based interventions can improve patient health outcomes while lowering total healthcare costs. Additionally, evaluating AI's effectiveness in comparison to conventional pharmacy systems can highlight its advantages and limitations, offering valuable direction for future enhancements. Identifying the key factors behind AI's effectiveness can help shape strategies to broaden its adoption within pharmacy systems and facilitate its integration into the wider healthcare framework.

5.6. Adjusting parameters

Based on the analyzed findings, appropriate modifications can be implemented to enhance the efficiency of AI in managing medication schedules and delivering personalized patient care. For instance, if medication adherence rates are found to be below expectations, strategies such as increasing reminder frequency or making reminder messages more engaging could be adopted. Similarly, if the system detects a significant number of drug interactions or adverse reactions, additional safety notifications or preventive measures can be introduced.

This refinement process should remain continuous, as ongoing data collection and analysis may uncover further areas for enhancement. Incorporating patient feedback is also vital to ensure that AI systems remain responsive to users' needs and preferences. Consistent updates and optimization of AI-enabled pharmacy platforms ultimately strengthen medication management, improve patient engagement, and lead to better overall healthcare outcomes.

5.7. Continuous monitoring and evaluation

Continuous monitoring and assessment are crucial to guarantee that AI consistently delivers useful assistance to patients and healthcare professionals. Routine evaluations enable pharmacists to detect problems and implement required modifications. If data analysis indicates ongoing adverse medication reactions despite AI interventions, adjustments can be implemented to improve the system's alarm systems. Likewise, if patients encounter difficulties with medication adherence, AI-enhanced communication tactics can be optimized to provide more tailored reminders and assistance. Ongoing monitoring allows healthcare providers to make informed decisions based on data and adjust AI capabilities to consistently enhance patient outcomes.

6. THE ROLE OF AI IN IMPROVING MEDICATION SAFETY AND THERAPEUTIC OUTCOMES

Integrating AI into pharmacy systems can transform the entire medication-use pathway—from prescribing and dispensing to monitoring and adherence—by removing long-standing inefficiencies in conventional processes. Through advanced analytical tools, AI enhances safety by identifying risks, optimizing drug selection, and supporting evidence-based decision-making. These mechanisms collectively demonstrate how AI can directly and indirectly improve medication safety and therapeutic outcomes on both the patient and system levels.

6.1. Reduction of error at the point of prescription and dispensation

AI can help reduce errors in dispensing by automating and complementing the error-prone manual methods. Devices such as NLP, capable of reading both handwritten and electronic prescriptions, can ensure that names, dosages, and intervals are not misread through manual entry [1], [4]. In addition, AI-facilitated CDSS conducts the real-time verification of extensive databases of drugs. These tools automatically identify warning signs, including:

- DDIs: detection of drug-drug interactions.
- Drug-allergy inconsistencies: notifying pharmacists when a medication ordered is inconsistent with known borrower allergies.
- Medicine under/over-dosing: comparing a prescribed dose with patient-specific factors such as age, weight, renal function, and more to prevent under-dosing or over-dosing.

By preventing mistakes before the release of the medication, AI serves as a valuable safety chain, counterbalancing the oversight of pharmacists and decreasing dependence solely on human alertness [2], [4].

6.2. Proactive monitoring and surveillance of medication safety

The utility of AI in medication safety continues beyond the bedside with proactive medication safety surveillance. Using ML to identify patterns in EHRs and patient-reported health monitoring data, it is possible to estimate the probability that a given individual would experience an adverse drug event. For instance, an AI system could recognize a patient receiving a new antihypertensive drug who is developing mild signs of renal insufficiency and intervene before it leads to an adverse event [3]. Moving from reactive surveillance to a proactive approach permits the pharmacist to manage risks before they become patient safety issues so that the total course of therapy is at lower risk.

6.3. Improving delivery with personalization and adherence support

The hallmark of drug therapy is successful therapeutic results, which are advanced by AI with individualized treatment and optimized compliance. AI-based algorithms could personalize treatment plans by assessing an individual's unique characteristics, such as genetics (pharmacogenomics), comorbidities, and lifestyle. Such data is advantageous for so-called precision medicine, where all patients receive the best medication with a low risk of side effects [6], [7]. Then, there's the issue of non-adherence, which AI is directly addressing. AI-driven interactive reminder systems and chatbots provide tailored context-based notifications and educational information to patients.

These systems may be dynamic, modifying the intensity of support based on patient engagement with protocols that are more intensive for those at high risk of missed doses. Research has demonstrated that tailored AI-guided interventions significantly improve MPR/PDC, adherence outcomes of significant interest [6], [12]. Better adherence has been linked with improved disease control, fewer hospital stays, and better long-term therapeutic outcomes, particularly when it comes to chronic diseases like diabetes or hypertension. If you turn the substrate of AI into BI or make another suggestion to sell, it is recommended for safe and effective medication journeys. Functions such as checking drug errors automatically, facilitating proactive risk management, and providing tailored care to ensure patients get appropriate medications all help in this regard. From a comprehensive angle, this method not only prevents harm but also helps heal.

7. KEY PHARMACY SYSTEM PARAMETERS MANAGED BY AI

Figure 2 depicts the primary roles that AI supports within pharmacy systems, such as medication management, patient monitoring, inventory management, and analysis of drug interactions. AI has the potential to transform the pharmacy field by enabling more efficient and personalized approaches to patient care. This transformation is achievable through advanced AI-based platforms that utilize deep learning algorithms to generate intelligent, human-like interactions while automating key functions within pharmacy operations [21]. AI can be applied to fundamental components of pharmacy systems, including prescription management, patient engagement, clinical monitoring, detection of drug interactions and adverse reactions, EHR integration, and comprehensive data analysis [13]. Harnessing AI across these domains enables healthcare professionals to deliver higher-quality patient care, achieve better clinical outcomes, and lower overall healthcare expenditures. The present study investigates the diverse applications of AI in pharmacy system management and its pivotal role in improving patient-centered healthcare delivery.

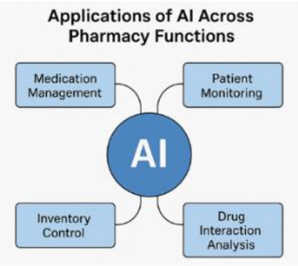


Figure 2. Applications of AI in pharmacy operations

8. CRITERIA FOR AI-ADMINISTERED PHARMACY SYSTEM PARAMETERS

8.1. Medication management

AI can monitor patient pharmaceutical protocols, guaranteeing accurate dosage, frequency, and time of administration. An effective application of AI in medication management is evident in diabetes therapy, where patients necessitate accurate modifications of insulin dosages [22]. AI-driven systems can issue reminders for medicine administration, track blood glucose levels via wearable devices, and offer tailored dosage suggestions. By incorporating real-time data, AI can aid patients in efficiently treating their disease, hence diminishing the likelihood of consequences such as diabetic ketoacidosis or retinopathy. Furthermore, AI can furnish healthcare providers with ongoing insights into patient compliance and health patterns, facilitating prompt interventions when necessary.

8.2. Patient communication

AI can improve patient participation by providing tailored medication instructions and reminders and addressing inquiries regarding prescriptions. For example, when a patient receives a new prescription and expresses apprehensions over its negative effects, AI-driven chatbots or virtual assistants can furnish comprehensive, evidence-based advice on proper administration, potential adverse effects, and essential precautions [23]. This technology guarantees that patients are adequately informed, enhancing compliance and alleviating medication-related anxiety. Moreover, AI can provide continuous help, enabling healthcare personnel to concentrate on more intricate instances while guaranteeing patients rapid access to dependable assistance.

8.3. Patient monitoring

AI systems can track patient adherence to prescribed treatment plans and notify healthcare providers of any deviations. A real-world application is the management of chronic conditions like diabetes or hypertension. AI-powered tools can integrate with wearable devices to monitor blood glucose levels or blood pressure, alerting patients when medication is due and notifying healthcare providers of any concerning trends [24]. If a patient consistently misses doses or experiences fluctuations in health metrics, AI can facilitate early intervention, helping to prevent complications and hospitalizations.

8.4. Drug interaction screening

AI has the capability to analyze and predict possible interactions between medications as well as between drugs and existing medical conditions, delivering instant notifications to both patients and healthcare professionals to prevent harmful outcomes. For example, if a patient taking antihypertensive medication is prescribed an antidepressant, AI can analyze the potential interaction between the two drugs. When a risk is identified, the system can issue warnings and suggest alternative therapies or dosage adjustments [25]. Additionally, AI can detect drug–disease interactions to ensure that prescribed treatments do not aggravate existing health conditions. By continuously analyzing prescription data, AI enhances patient safety and minimizes the likelihood of adverse drug reactions.

8.5. Adverse drug reaction detection

AI can oversee patients for negative drug reactions by scrutinizing health data and detecting early indicators. For instance, if a patient on antihypertensive medicine exhibits irregular heart rate variations, AI can analyze this data against baseline levels to identify probable adverse drug reactions [26]. The technology might subsequently inform the healthcare provider and suggest modifications to the treatment plan. AI can gather patient-reported symptoms, enhancing the capacity to identify bad reactions promptly and implement preventive strategies.

8.6. Integration with electronic health records

AI can be effectively integrated with EHR systems to offer healthcare professionals real-time insights into patients' medication use and treatment progress. A major application of this integration lies in medication reconciliation, which ensures the accuracy of a patient's complete medication list [27]. AI is capable of analyzing a patient's medication history, identifying inconsistencies, and suggesting suitable adjustments. This capability not only lessens the manual workload for healthcare professionals but also minimizes the chances of medication errors and enhances overall patient safety. In addition, AI can alert healthcare providers to potential omissions or inaccuracies in prescriptions, thereby increasing the accuracy and efficiency of patient care.

8.7. Data analytics for healthcare insights

AI can process extensive amounts of patient data to uncover patterns and trends associated with medication adherence, possible drug interactions, and adverse drug reactions. AI-driven analytics can monitor pharmaceutical adherence rates among various patient populations, pinpointing prevalent obstacles to compliance, such as intricate dosing regimens or adverse effects [14]. Utilizing these insights, healthcare providers can develop interventions, like personalized reminders or educational programs, to enhance adherence and health outcomes. Furthermore, data analytics can identify overarching trends in pharmacy practice, facilitating the formulation of more efficacious treatment methods and support systems.

9. PROSPECTIVE APPLICATIONS OF AI IN PHARMACY SYSTEM

AI-powered virtual assistants are redefining the landscape of pharmacy systems by delivering instant, personalized support to both patients and healthcare providers. Utilizing sophisticated NLP and ML models, these systems can understand user queries, interpret medical information, and generate accurate, context-aware responses in real time. AI now permeates many aspects of pharmacy practice—from managing prescriptions and monitoring patient health to identifying drug interactions and analyzing clinical data. By incorporating

AI-driven tools, healthcare institutions can improve patient outcomes, increase operational efficiency, and reduce overall medical costs. This paper examines the extensive roles of AI within pharmacy systems and its transformative influence on the evolution of modern healthcare [11].

AI is revolutionizing modern pharmacy practice by introducing advanced innovations that span every aspect of the field. From accelerating drug discovery to delivering tailored patient care, AI optimizes and automates critical operations such as pharmaceutical formulation, therapeutic decision-making, medication supervision, and continuous patient tracking. Through its ability to process and interpret extensive clinical datasets, AI empowers pharmacists to make data-driven, precise, and timely clinical decisions. This technological advancement not only enhances treatment outcomes but also improves workflow efficiency and reduces overall healthcare costs. The adoption of AI in pharmacy marks a pivotal shift toward a more intelligent, personalized, and sustainable healthcare system [28].

Alongside its many advantages, AI plays a crucial role in recognizing potential drug interactions, adverse reactions, and other safety concerns. By analyzing comprehensive patient information—including medical history, genetic characteristics, and medication records—AI-based systems can detect potential risks and deliver personalized guidance to optimize pharmacotherapy. This capability reduces the likelihood of medication errors and enhances overall patient safety. In addition, AI aids the drug discovery process by examining large-scale datasets to identify viable drug targets and predict the potential efficacy of new compounds, thus accelerating development timelines and significantly cutting research and development costs.

A major domain in which AI can bring transformative change is the management of chronic diseases. Intelligent AI-based platforms can continuously monitor patient health metrics—such as vital signs, symptom progression, and adherence to prescribed therapies—to identify potential complications before they escalate. By enabling early detection and timely clinical intervention, this predictive approach enhances long-term patient outcomes while reducing costs associated with hospitalizations and emergency care. The integration of AI within pharmacy practice stands to redefine healthcare by promoting precision-driven, efficient, and patient-centered services. As AI technologies advance, their role in pharmacy will continue to expand, fostering groundbreaking innovations that shape the future of healthcare delivery.

10. SUPPORTING PHARMACY SYSTEMS THROUGH AI ALGORITHMS

The efficiency of AI in pharmacy systems is based on the development of ML and deep learning techniques. These algorithms enhance patient care by enabling automation, precision, and predictive analysis. The following is an exposition of key AI algorithms employed in pharmacy [8], [13], [15]–[22].

10.1. Decision support systems

Decision support systems (DSS) in pharmacy are broadly categorized into two types: prescriptive decision support systems (PDSS) and descriptive decision support systems (DDSS). PDSS go beyond simply providing data—they analyze multiple variables and generate actionable recommendations to guide pharmacists in making optimal decisions. For instance, PDSS tools may suggest the most appropriate medication regimen for a patient based on their medical history, comorbidities, and current prescriptions, thereby supporting personalized therapy. In the operational context, PDSS can recommend cost-effective inventory management strategies by analyzing purchasing patterns, supplier performance, and seasonal variations in drug demand. These systems often incorporate optimization algorithms, predictive analytics, and ML to propose solutions that align with clinical goals and economic efficiency.

On the other hand, DDSS focus on collecting, organizing, and presenting information about past or current events without directly suggesting a course of action. These systems are valuable for understanding trends and supporting situational awareness. For example, a DDSS might provide insights into historical medication usage patterns within a healthcare facility, highlight the incidence and distribution of certain diseases across geographic regions, or display real-time data on drug consumption and patient demographics. By summarizing complex datasets into understandable formats—such as dashboards, charts, and reports—DDSS tools enable pharmacists and healthcare administrators to identify areas of concern, assess performance, and inform future planning.

Together, PDSS and DDSS serve complementary roles in pharmacy practice. While DDSS aids in understanding "what is" or "what was," PDSS focuses on "what should be done." The integration of both systems enhances evidence-based decision-making, streamlines workflows, and ultimately contributes to safer, more effective, and economically sustainable pharmaceutical care.

10.2. Machine learning models

ML models, including decision trees, support vector machines (SVM), and random forests, play a pivotal role in transforming pharmacy operations and enhancing clinical outcomes. These algorithms are employed to optimize prescription processes by analyzing large datasets derived from EHRs, medication histories, and patient demographics. Decision trees and random forests are particularly effective in handling structured data, enabling them to assist pharmacists in selecting the most appropriate medications based on patient-specific factors such as age, renal function, comorbidities, and drug tolerance. These models can swiftly identify patterns that may not be immediately evident to human clinicians, such as subtle drug-drug interactions or contraindications.

SVM known for their accuracy in classification tasks, are utilized in predictive analytics to assess the likelihood of patient adherence to prescribed medication regimens. By analyzing behavioral data, prescription refill histories, and socioeconomic indicators, SVM models can predict non-compliance and trigger targeted interventions, such as patient counseling or automated reminders, to improve adherence rates. Furthermore, ensemble models like random forests, which combine multiple decision trees to improve prediction accuracy and reduce overfitting, are increasingly applied in pharmacovigilance to detect potential adverse drug reactions or unexpected side effects based on post-marketing surveillance data. Collectively, these ML tools contribute to safer and more efficient pharmacy practices by enabling real-time risk assessment, supporting evidence-based prescribing, and tailoring interventions to individual patient needs. As these technologies continue to evolve, their integration into CDSS promises to enhance the precision and personalization of pharmaceutical care, ultimately improving patient outcomes while reducing medication-related errors and costs.

10.3. Deep learning techniques

Among the deep learning models, convolutional neural networks (CNNs) and recurrent neural networks (RNNs) are extensively employed in the healthcare and pharmaceutical sectors due to their ability to process and interpret complex, high-dimensional data. CNNs, originally designed for image recognition tasks, have been successfully adapted for use in pharmaceutical research, particularly in analyzing biomedical images such as X-rays, MRI scans, and histopathological slides. In the pharmaceutical context, CNNs are also utilized to analyze the structural properties of drug molecules through imaging-based representations or chemical structure diagrams, aiding in drug discovery and compound screening processes. Their layered architecture enables them to detect intricate spatial patterns, making them highly effective for identifying anomalies or disease markers associated with specific conditions.

On the other hand, RNNs are particularly suited for sequential data analysis, making them ideal for examining time-dependent patient information such as EHRs, medication histories, and treatment timelines. Through their ability to retain contextual information across time steps, RNNs can model patient trajectories, forecast disease progression, and predict potential medication outcomes. For example, RNNs can be trained to analyze sequences of prescriptions to identify patterns that may indicate adverse drug reactions, treatment inefficacy, or non-adherence.

Together, CNNs and RNNs contribute significantly to the accuracy of medical diagnosis and the personalization of therapy. By integrating diverse sources of data—ranging from imaging and genomic information to longitudinal patient records—these models support clinicians in making informed decisions, identifying high-risk patients, and recommending the most effective treatment plans. Additionally, when combined with attention mechanisms or embedded in larger architectures such as transformers, these models exhibit even greater performance in understanding complex clinical narratives and ensuring safer pharmaceutical interventions. As deep learning continues to advance, its incorporation into pharmacy practice holds immense potential to revolutionize drug development, patient care, and clinical diagnostics through data-driven precision medicine.

10.4. Natural language processing

NLP, a subfield of AI, plays a crucial role in enhancing human-computer interactions within pharmacy practice by enabling AI-based chatbots and virtual assistants to understand, process, and respond to human language in a clinically meaningful way. NLP empowers these systems to comprehend patient queries posed in natural, often unstructured language—whether spoken or typed—and extract relevant medical information such as symptoms, medication names, dosages, and treatment histories. This capability allows virtual assistants to provide accurate, context-aware responses to patient questions related to prescriptions, dosage instructions, potential drug interactions, side effects, and refill reminders.

In addition to answering routine queries, NLP models can interpret clinical notes, EHRs, and prescription data to identify inconsistencies or potential safety risks. For example, an NLP-powered system can detect if a prescribed medication is contraindicated based on a patient's recorded allergies or medical history, thereby alerting healthcare providers before dispensing. These tools also assist pharmacists in automating documentation, improving efficiency in pharmacy workflows, and reducing cognitive load during patient counseling.

Furthermore, multilingual NLP capabilities allow these systems to serve diverse patient populations by translating medical information accurately, thus bridging communication gaps and enhancing healthcare accessibility for non-native speakers. Advanced NLP models, especially those integrated with transformerbased architectures such as BERT and GPT, can also analyze sentiment and detect nuances in patient language, helping to identify underlying concerns, such as anxiety about medications or non-adherence tendencies. As NLP technologies continue to evolve, their integration into pharmacy platforms not only streamlines operations but also enhances patient engagement, education, and safety. Ultimately, by facilitating more natural, intuitive, and intelligent interactions between patients and pharmacy systems, NLP is a cornerstone in advancing personalized and patient-centered pharmaceutical care.

10.5. Reinforcement learning

Reinforcement learning (RL) models significantly enhance pharmacy automation by enabling systems to learn optimal decision-making strategies through continuous interaction with their environment. In the context of inventory management, RL algorithms can dynamically adjust stock levels based on real-time demand, expiration dates, and supply chain fluctuations, reducing waste and ensuring timely availability of essential medications. These models learn from historical data and current trends to predict future needs, making inventory control more responsive and cost-effective.

Additionally, RL models contribute to the personalization of patient care by generating more accurate and adaptive treatment recommendations. By incorporating real-time patient feedback—such as adherence patterns, reported side effects, and biometric data—RL systems iteratively refine therapeutic strategies to achieve better health outcomes. Unlike traditional ML approaches, RL can evaluate the long-term consequences of treatment decisions, which is particularly useful in managing chronic conditions where patient responses evolve over time. Through ongoing learning and optimization, RL models help automate complex decision-making processes in pharmacy practice, leading to smarter resource allocation, improved medication adherence, and enhanced patient satisfaction. As RL technologies advance, their integration into healthcare systems holds the potential to revolutionize both operational efficiency and clinical effectiveness in pharmacy settings.

10.6. Federated learning

Federated learning enables different healthcare institutions to jointly train AI models without exchanging patient data. This technique reduces the data-sharing risks while enhancing the AI performance and productivity across different healthcare institutions. The aforementioned AI algorithms, when combined together, can help pharmacy systems in better management of medications, decrease chances of errors, and offer improved and science-based approaches to healthcare delivery.

11. COMPARISON BETWEEN AI AND TRADITIONAL PHARMACY SYSTEMS

The application of AI in pharmacy systems marks a shift from conventional manual processes to intelligent, data-driven models. Understanding this transition requires examining how AI-enabled workflows differ from traditional approaches in terms of accuracy, efficiency, and clinical value. By comparing the key features of both systems, it becomes possible to evaluate the extent to which AI enhances safety, decision-making, and overall pharmacy performance.

11.1. Efficiency and workflow optimization

Traditional pharmacy systems rely on manual data entry, pharmacist verification, and in-person consultations, making the workflow slower, less efficient, and more prone to human error. In contrast, AI-enabled pharmacy systems integrate ML, automation, and real-time analytics to streamline tasks and support clinical decision-making. As a result, prescription processing becomes faster and more accurate, ultimately improving operational efficiency and patient safety.

11.2. Accuracy and error reduction

Medication errors remain a major concern in traditional pharmacy systems, largely because manual data entry and pharmacist validation are vulnerable to oversight. AI-enabled systems address this challenge by applying predictive analytics, NLP, and deep learning models capable of detecting risky prescriptions, harmful interactions, and dosage irregularities with greater precision. This enhanced level of automated verification significantly reduces the likelihood of preventable medication mistakes and improves overall patient safety.

11.3. Personalization and patient engagement

Conventional pharmacy systems offer limited personalization and often rely on generalized treatment protocols that do not fully consider individual patient needs. In contrast, AI-driven systems analyze comprehensive patient data to generate tailored therapeutic recommendations and improve clinical decision-making. Additionally, AI-powered applications provide personalized medication reminders and adherence support, resulting in more effective and patient-centered care.

11.4. Drug interaction and safety monitoring

Classic pharmacy systems rely solely on pharmacists to manually review patients' medication histories, which can limit the ability to detect complex or evolving drug interactions. In contrast, AI-based systems continuously analyze patient data in real time, identifying potential risks and hazardous combinations far more efficiently. This real-time monitoring—such as that enabled by health intelligence algorithms (HIA)—significantly enhances overall medication safety and supports more proactive clinical interventions.

11.5. Scalability and accessibility

AI-based pharmacy solutions enable scalable telepharmacy services, offering remote consultations, digital medication management, and automated prescription delivery. These capabilities allow pharmacies to extend care to a wider population, including patients in rural or underserved regions. In contrast, traditional pharmacy models depend heavily on physical locations and in-person visits, limiting accessibility and reducing the reach of essential healthcare services.

11.6. Cost implications

This is because traditional pharmacies have high operating costs as a result of employment, processing, and management of stock. It cuts costs through optimal management of inventory, minimizing wastage, and reducing costs that would otherwise have been incurred in the course of management. This, in one way or another, lowers the costs of health care to the providers as well as the consumers. Pharmacy AI systems are driven by AI and therefore are accurate, efficient, and patient-centered. But for integration to be optimal, ethical concerns, regulatory challenges, and the need for human oversight must be addressed. Table 3 compares traditional pharmacy systems with AI-enabled solutions, highlighting differences in workflow efficiency, personalization, safety monitoring, accessibility, and cost-effectiveness. It illustrates the advantages of AI in reducing errors, improving adherence, and supporting telepharmacy services.

Table 3. AI vs. traditional pharmacy systems

Feature	Traditional pharmacy	AI-driven pharmacy
Prescription processing	Manual entry and verification	Automated NLP-based processing
Drug interaction checks	Pharmacist review	AI-driven real-time alerts
Personalization	Standardized treatment	Personalized medication plans
Medication adherence	Patient-driven	AI-powered reminders and tracking
Error detection	Human oversight	Predictive analytics and ML models
Accessibility	In-person visits required	Telepharmacy and remote monitoring
Cost efficiency	Higher staffing and admin costs	Reduced labor and operational costs

12. ETHICAL CHALLENGES

The integration of AI into pharmacy systems raises several ethical considerations that must be carefully managed to ensure responsible and safe implementation [11], [28]. As illustrated in Figure 3, these concerns include data privacy, algorithmic bias, transparency, and the protection of patient autonomy through informed consent. Addressing these challenges is essential to building trust in AI-driven pharmacy practices and safeguarding patient well-being.

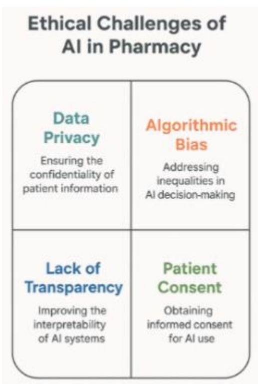


Figure 3. Ethical challenges of AI in pharmacy

12.1. Data privacy and security

AI systems depend on extensive collections of sensitive patient information, such as medical records, genetic data, and medication histories. Any unauthorized access, data breach, or misuse of this information can jeopardize patient privacy. Adhering to data protection laws like HIPAA in the United States and GDPR in the European Union is crucial; however, global data sharing in healthcare introduces additional compliance challenges. Implementing strong encryption methods, data anonymization practices, and rigorous access control measures is vital to safeguard patient confidentiality and reduce associated risks [29]–[31].

12.2. Informed consent

Patients may lack awareness of how AI algorithms use their data to generate recommendations. Traditional consent forms often fail to clarify the extent of AI's role in decision-making, raising concerns about transparency. Ethical implementation requires clear communication to patients about how their data will be processed, stored, and utilized by AI systems, enabling truly informed consent.

12.3. Algorithmic bias and equity

AI models developed on biased or unrepresentative datasets may sustain inequities in healthcare. The underrepresentation of minority groups in training data may result in erroneous dosage recommendations or neglected medication interactions for these populations. Proactive approaches, such as inspecting datasets for diversity and employing bias-correction algorithms, are essential to guarantee equal outcomes. Moreover, socioeconomic inequalities in access to AI-driven tools threaten to exacerbate existing healthcare disparities, especially for rural or low-income patients.

12.4. Transparency and explainability

Numerous AI algorithms, especially deep learning models, function as "black boxes," complicating the interpretation of their decision-making processes. Pharmacists and patients may be reluctant to believe advice without comprehending its underlying logic. Creating XAI frameworks and delivering comprehensible explanations for outcomes can improve transparency and promote acceptance.

13. DISCUSSION

Incorporating AI into pharmacy systems creates groundbreaking possibilities for advancing patient safety, streamlining operations, and promoting individualized care. Intelligent AI applications enhance precision in medication dispensing, minimize the risk of prescription-related mistakes, and empower pharmacists to deliver tailored therapeutic guidance and support. By automating time-consuming activities—such as validating prescriptions, managing stock, and processing routine data—AI allows pharmacists to focus on clinical evaluation and meaningful patient interactions. This shift not only elevates the quality of pharmaceutical services but also leads to more effective and patient-centered healthcare outcomes.

13.1. Integration with EHR systems, mobile health applications, and pharmacist decision support tools

A crucial component of implementing AI-driven pharmacy systems is achieving seamless interoperability with EHRs, mobile health applications, and pharmacist decision support tools (PDSTs). EHR integration allows pharmacists to access complete medication histories, allergy data, laboratory results, and comorbidities in real time. This enables robust medication reconciliation, automatic detection of discrepancies, and proactive identification of drug–drug or drug–disease interactions. Such integration reduces manual workload, enhances prescription safety, and supports evidence-based therapeutic decisions [32].

Mobile health applications serve as patient-facing extensions of pharmacy systems, supporting adherence monitoring, symptom reporting, and two-way communication. AI-enabled personalization allows context-aware reminders, educational notifications, and adaptive adherence interventions. For example, if wearable devices indicate a deviation in blood glucose levels or blood pressure, the system can notify both the patient and pharmacist for timely action, strengthening self-management of chronic conditions [33].

PDSTs combine insights from EHR and mobile health data to generate prioritized, explainable recommendations. These tools leverage predictive analytics and NLP to minimize alert fatigue, highlight clinically significant interactions, and optimize workflow efficiency. In doing so, PDSTs preserve pharmacists' central role in clinical oversight while improving decision accuracy and reducing the risk of adverse drug events. Together, these components create a connected and intelligent ecosystem that delivers continuity of care across settings, supports regulatory compliance (HIPAA/GDPR), and empowers patients through better engagement. Future work should focus on interoperability standards such as Health Level Seven International (HL7) FHIR (fast healthcare interoperability resources) HL7 FHIR, cybersecurity safeguards, and usability research to ensure that integrated systems remain secure, scalable, and user-friendly.

13.2. Broader implications for pharmacy practice

Beyond integration, AI holds significant promise for accelerating drug development and enhancing therapeutic outcomes. By rapidly analyzing large biomedical datasets, AI tools can identify novel drug targets, predict pharmacokinetic profiles, and reduce the cost and duration of clinical trials. This can accelerate the delivery of new, effective treatments to patients [33].

Furthermore, AI-driven systems play a vital role in chronic disease management, enabling early detection of complications, improving adherence, and lowering hospitalization rates. Such capabilities are particularly relevant in managing conditions such as diabetes, hypertension, and heart failure, where continuous monitoring and timely interventions directly affect patient prognosis. Finally, integrating AI with pharmacy systems supports the creation of new analytical tools for processing extensive patient data and generating actionable insights. As these technologies continue to evolve, they will further redefine pharmacy practice, shifting the pharmacist's role toward personalized care and advanced clinical decision-making.

14. CONCLUSION

The adoption of AI in pharmacy systems represents a major shift toward intelligent, connected, and patient-centered healthcare delivery. By automating essential tasks such as prescription interpretation, drug interaction screening, inventory optimization, and adherence monitoring, AI minimizes human error, improves workflow efficiency, and enables pharmacists to dedicate more time to clinical judgment and patient counseling. Its capacity to integrate data from EHRs, drug knowledge bases, and real-time PGHD allows for the creation of highly personalized treatment plans and proactive risk mitigation strategies. Integration with EHRs, mobile health applications, and PDSTs ensures seamless data exchange, facilitating real-time medication reconciliation, detection of discrepancies, and prompt clinical interventions. This connected ecosystem enhances patient engagement through adaptive reminders, educational content, and two-way communication channels, ultimately improving adherence rates, reducing adverse events, and optimizing therapeutic outcomes across both acute and chronic care settings. Nevertheless, the successful and responsible implementation of AI-powered pharmacy systems requires careful consideration of ethical, legal, and technical challenges. Issues such as data privacy, algorithmic bias, explainability of AI models, and adherence to regulatory frameworks like HIPAA and GDPR must be addressed to build trust among patients, pharmacists, and policymakers. Robust governance mechanisms, bias detection and mitigation strategies, and the adoption of interoperability standards such as HL7 FHIR will be crucial to ensuring equitable access and safe deployment of these systems. Future research should emphasize longitudinal, real-world studies to evaluate patient satisfaction, clinical outcomes, and economic impact, as well as explore innovations such as federated learning and privacy-preserving analytics for secure data sharing. By aligning technological progress with ethical safeguards and clinical best practices, AI-driven pharmacy systems can become a cornerstone of modern healthcare, delivering scalable, sustainable, and high-quality care to diverse patient populations worldwide.

FUNDING INFORMATION

Authors state no funding involved.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Adi El-Dalahmeh	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	
Nevien Nedal		✓				✓		✓	✓	✓	✓	✓		
Khulood Abu Maria	✓		✓	✓			✓			✓	✓		✓	✓
Sara Abu Tarboosh		✓				✓		✓	✓	✓	✓	✓		

C : **C**onceptualization	I : **I**nvestigation	Vi : **Vi**sualization
M : **M**ethodology	R : **R**esources	Su : **Su**pervision
So : **So**ftware	D : **D**ata Curation	P : **P**roject administration
Va : **Va**lidation	O : Writing - **O**riginal Draft	Fu : **Fu**nding acquisition
Fo : **Fo**rmal analysis	E : Writing - Review and **E**diting	

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author.

REFERENCES

[1] S. H. Chalasani, J. Syed, M. Ramesh, V. Patil, and T. P. Kumar, "Artificial intelligence in the field of pharmacy practice: A literature review," *Exploratory Research in Clinical and Social Pharmacy*, vol. 12, 2023, doi: 10.1016/j.rcsop.2023.100346.

[2] H. E. Hasan, D. Jaber, O. F. Khabour, and K. H. Alzoubi, "Ethical considerations and concerns in the implementation of AI in pharmacy practice: A cross-sectional study," *BMC Medical Ethics*, vol. 25, no. 1, 2024, doi: 10.1186/s12910-024-00955-4.

[3] A. Flynn, "Using artificial intelligence in health-system pharmacy practice: Finding new patterns that matter," *American Journal of Health-System Pharmacy*, vol. 76, no. 9, pp. 622–627, 2019, doi: 10.1093/ajhp/zxz050.

[4] F. Ranchon, S. Chanoine, S. L. -Lacroix, J. L. Bosson, A. M. -Gaudry, and P. Bedouch, "Development of artificial intelligence powered apps and tools for clinical pharmacy services: A systematic review," *International Journal of Medical Informatics*, vol. 172, 2023, doi: 10.1016/j.ijmedinf.2023.104983.

[5] A. S. Jarab *et al.*, "Artificial intelligence in pharmacy practice: Attitude and willingness of the community pharmacists and the barriers for its implementation," *Saudi Pharmaceutical Journal*, vol. 31, no. 8, 2023, doi: 10.1016/j.jsps.2023.101700.

[6] T. Sharma, A. Mankoo, and V. Sood, "Artificial intelligence in advanced pharmacy," *International Journal of Scientific Research Archive*, vol. 2, no. 1, pp. 47–54, 2021, doi: 10.30574/ijsra.2021.2.1.0050.

[7] M. I. A. Fahim, T. S. Tonny, and A. Al Noman, "Realizing the potential of AI in pharmacy practice: Barriers and pathways to adoption," *Intelligent Pharmacy*, vol. 2, no. 3, pp. 308–311, 2024, doi: 10.55629/ip.2024.020303.

[8] S. B. Sridhar, M. S. Karattuthodi, and S. A. Parakkal, "Role of artificial intelligence in clinical and hospital pharmacy," in *Application of Artificial Intelligence in Neurological Disorders*, Singapore: Springer Nature Singapore, 2024, pp. 229–259, doi: 10.1007/978-981-99-6828-5_12.

[9] M. Stasevych and V. Zvarych, "Innovative robotic technologies and artificial intelligence in pharmacy and medicine: Paving the way for the future of health care—A review," *Big Data and Cognitive Computing*, vol. 7, no. 3, 2023, doi: 10.3390/bdcc7030147.

[10] M. A. Raza and S. Aziz, "Transformative potential of artificial intelligence in pharmacy practice," *Saudi Pharmaceutical Journal*, vol. 31, no. 9, 2023, doi: 10.1016/j.jsps.2023.101706.

[11] H. K. Jin, H. E. Lee, and E. Kim, "Performance of ChatGPT-3.5 and GPT-4 in national licensing examinations for medicine, pharmacy, dentistry, and nursing: A systematic review and meta-analysis," *BMC Medical Education*, vol. 24, no. 1, 2024, doi: 10.1186/s12909-024-05192-x.

[12] D. Roosan, P. Padua, R. Khan, H. Khan, C. Verzosa, and Y. Wu, "Effectiveness of ChatGPT in clinical pharmacy and the role of artificial intelligence in medication therapy management," *Journal of the American Pharmacists Association*, vol. 64, no. 2, pp. 422–428, 2024, doi: 10.1016/j.japh.2023.12.012.

[13] S. Smoke, "Artificial intelligence in pharmacy: A guide for clinicians," *American Journal of Health-System Pharmacy*, vol. 81, no. 14, pp. 641–646, 2024, doi: 10.1093/ajhp/zxaf059.

[14] M. Sallam, N. A. Salim, M. Barakat, and B. Ala'a, "ChatGPT applications in medical, dental, pharmacy, and public health education: A descriptive study highlighting the advantages and limitations," *Narra Journal*, vol. 3, no. 1, 2023, doi: 10.52225/narra.v3i1.103.

[15] S. Dentzer, "Creating the future of artificial intelligence in health-system pharmacy," *American Journal of Health-System Pharmacy*, vol. 76, no. 24, pp. 1995–1996, 2019, doi: 10.1093/ajhp/zxz249.

[16] Z. Al-Dujaili, S. Omari, J. Pillai, and A. Al Faraj, "Assessing the accuracy and consistency of ChatGPT in clinical pharmacy management: A preliminary analysis with clinical pharmacy experts worldwide," *Research in Social and Administrative Pharmacy*, vol. 19, no. 12, pp. 1590–1594, 2023, doi: 10.1016/j.sapharm.2023.09.003.

[17] Y. Zhu, D. Han, S. Chen, F. Zeng, and C. Wang, "How can ChatGPT benefit pharmacy: a case report on review writing," *Preprints*, pp. 1–7, 2023, doi: 10.20944/preprints202302.0324.v1.

[18] S. J. Trenfield *et al.*, "Advancing pharmacy and healthcare with virtual digital technologies," *Advanced Drug Delivery Reviews*, vol. 182, 2022, doi: 10.1016/j.addr.2022.114098.

[19] S. D. Nelson, "Artificial intelligence and the future of pharmacy," *American Journal of Health-System Pharmacy*, vol. 81, no. 4, pp. 83–84, 2024, doi: 10.1093/ajhp/zxaf001.

[20] N. V Kalayil, S. S. D'Souza, S. Y. Khan, and P. Paul, "Artificial intelligence in pharmacy drug design," *Artificial Intelligence*, vol. 15, no. 4, 2022, doi: 10.57238/ai.2022.15.4.001.

[21] P. K. Donepudi, "AI and machine learning in retail pharmacy: Systematic review of related literature," *ABC Journal of Advanced Research*, vol. 7, no. 2, pp. 109–112, 2018, doi: 10.18034/abcjar.v7i2.79.

[22] A. A. Saeed *et al.*, "Perceptions of pharmacy students toward artificial intelligence in pharmacy," *Matrix Science Pharma*, vol. 8, no. 2, pp. 31–36, 2024, doi: 10.26480/msp.02.2024.31.36.

[23] P. S. Mishra, R. Mishra, S. Pingali, and R. Malviya, "Advancement in artificial intelligence: Insights and future vision for the pharmacy profession," in *Pharmaceutical Industry 4.0: Future, Challenges & Application*, River Publishers, 2023, pp. 367–381, doi: 10.1201/9781003333341-20.

[24] S. Mishra, "The transformative role of artificial intelligence in pharmacy: Innovations and applications," *Futuristic Trends in Pharmacy & Nursing*, 2024, pp. 389-398.

[25] X. Huang, D. Estau, X. Liu, Y. Yu, J. Qin, and Z. Li, "Evaluating the performance of ChatGPT in clinical pharmacy: A comparative study of ChatGPT and clinical pharmacists," *British Journal of Clinical Pharmacology*, vol. 90, no. 1, pp. 232–238, 2024, doi: 10.1111/bcp.15957.

[26] E. J. Kostić, D. A. Pavlović, and M. D. Živković, "Applications of artificial intelligence in medicine and pharmacy: Ethical aspects," *Acta Medica Medianae*, vol. 58, no. 3, pp. 128–137, 2019, doi: 10.5633/amm.2019.0318.

[27] A. Almeman, "The digital transformation in pharmacy: Embracing online platforms and the cosmeceutical paradigm shift," *Journal of Health, Population and Nutrition*, vol. 43, no. 1, 2024, doi: 10.1186/s41043-024-00530-7.

[28] J. Atkinson, "Advances in pharmacy practice: A look towards the future," *Pharmacy*, vol. 10, no. 5, 2022, doi: 10.3390/pharmacy10050125.

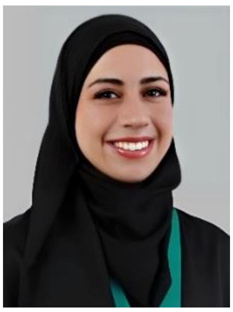
[29] S. AlZu'Bi, M. Almiani, and Y. Jararweh, "Agentic AI for healthcare: Solutions to intelligent patient care," in *Proceedings of the 2025 12th International Conference on Information Technology (ICIT)*, 2025, pp. 33–38, doi: 10.1109/ICIT60871.2025.1234567.
[30] M. Al Rawajbeh and H. Al-Zoubi, "Implementing the concept of smart cities in Amman: Reality and aspirations review," in *2024 IEEE/ACS 21st International Conference on Computer Systems and Applications (AICCSA)*, 2024, pp. 1–7, doi: 10.1109/AICCSA60164.2024.10460933.
[31] A. Z. Ala'M, K. Sundus, and T. Kanan, "A comprehensive survey on intrusion detection systems in IoT: Challenges and future directions," in *2025 12th International Conference on Information Technology (ICIT)*, 2025, pp. 213–218, doi: 10.1109/ICIT60871.2025.1234789.
[32] N. Seifi, E. Ghoodjani, S. S. Majd, A. Maleki, and S. Khamoushi, "Evaluation and prioritization of artificial intelligence integrated block chain factors in healthcare supply chain: A hybrid decision making approach," *Computational Decision Making: International Journal*, vol. 2, pp. 374–405, 2025, doi: 10.54216/CDMIJ.020204.
[33] L. M. Amugongo, A. Kriebitz, A. Boch, and C. Lütge, "Operationalising AI ethics through the agile software development lifecycle: A case study of AI-enabled mobile health applications," *AI Ethics*, vol. 5, no. 1, pp. 227–244, 2025, doi: 10.1007/s43681-024-00435-6.

BIOGRAPHIES OF AUTHORS

Adi El-Dalahmeh is an Assistance Professor in the Department of Cybersecurity, Faculty of Science and Information Technology, Al-Zaytoonah University of Jordan (ZUJ). He is a researcher and academic specializing in vehicular ad hoc net-works (VANETs), network security, and software-defined networking (SDN) for intelligent transportation systems. His work focuses on intrusion detection systems, lattice-based cryptography, dynamic pseudonym management, and the integration of blockchain and federated learning for VANET security. He has authored and co-authored peer-reviewed articles in IET Networks, IEEE venues, and other high-impact journals, advancing scalable, lightweight security frameworks for real-time vehicular environments. He can be contacted at email: A.eldalahmeh@zuj.edu.jo.

Nevien Nedal is a Master of Science (M.Sc.) student in Pharmacy at the Faculty of Pharmacy, Al-Zaytoonah University of Jordan. Her academic focus lies in Medicinal Chemistry and Pharmacognosy, with a particular interest in computational drug design, molecular docking, and the synthesis of bioactive compounds. She can be contacted at email: 202427044@std-zuj.edu.jo.

Khulood Abu Maria is an Associate Professor in the Department of Computer Science, Faculty of Science and Information Technology, Al-Zaytoonah University of Jordan (ZUJ). She received her B.Sc. in Computer Science from Mutah University, Jordan, in 1992, and her Ph.D. in Computer Information Systems from the Arab Academy for Banking and Financial Sciences–University of Science and Technology, in 2008. From 1992 to 2006, she served as a programmer, analyst, network administrator, and IT manager at Petra Engineering Industries Co. She was a part-time instructor of Management Information Systems at Al-Isra University from 2008 to 2009, before joining ZUJ in 2009, where she continues to teach and conduct research. Her research interests include information systems, software engineering, artificial intelligence, security, smart systems, and agent-based systems. She can be contacted at email: khulood@zuj.edu.jo.



Sara Abu Tarboosh is now pursuing her master's degree in pharmaceutical sciences at Al-Zaytoonah University of Jordan (ZUJ). Her current research is on personalized medication delivery systems that are 3D printed, specifically mucoadhesive nasal films. She aims to use machine learning and design of experiments to anticipate drug release behavior and optimize printing parameters. She is committed to enhancing personalized medicine and is interested in pharmaceutical technology, bioprinting, and artificial intelligence in pharmacy. She can be contacted at email: sara31122000@yahoo.com.