

Original Research

AI-Driven pharmacy practice: Unleashing the revolutionary potential in medication management, pharmacy workflow, and patient care

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Abstract

The integration of Artificial Intelligence (AI) in pharmacy practice holds great potential to revolutionize healthcare delivery and improve patient outcomes. AI can assist pharmacists in optimizing medication selection, predicting adverse drug events and drug interactions, enhancing inventory management, and automating prescription verification. Moreover, AI-driven systems can facilitate personalized counseling and lifestyle management for patients, promoting treatment adherence and better health outcomes. However, the implementation of AI in pharmacy practice faces challenges, including ethical considerations, data privacy, and the need for comprehensive training for pharmacists. This review article explores how AI technology is revolutionizing medication management, pharmacist workflow, and patient care in pharmacy practice. Authors also explore the various applications and recommendations to overcome the barriers, providing valuable insights for pharmacists, healthcare professionals and policymakers..

Keywords: artificial intelligence; AI; machine learning; medication management; natural language processing; optimized medication selection; pharmacists

INTRODUCTION

Artificial intelligence (AI) is the digital analog of the human brain, that will facilitate the performance of conventional tasks that need human knowledge, like problem-solving, planning, learning, teaching, language comprehension, and perception.^{1,2} The invention of such a powerful and evolutionary technology has emerged in healthcare with great promises of revolutionizing the practice, including pharmacy practice. AI can improve patient care, optimize drug management, and improve healthcare delivery through its capacity to process massive volumes of data, determine patterns, and provide insight.^{3,4}

Pharmacists play a crucial role in providing patient-centered care and ensuring effective and safe use of medications.⁵ Medication errors, resulting from the heavy workload placed on pharmacists, can have serious consequences on patient well-being. These errors include medication and patient identification mistakes, such as dispensing the wrong medication, incorrect dosing, frequency, or dosage form, and errors in identifying the patient's medication needs.^{6,7} The integration of AI into pharmacy practice allows assisting

pharmacists in their decision-making process and enhances patient outcomes.⁸ Medication optimization is one of the important areas in pharmacy practice where AI can show its capabilities. The algorithm technique aids in identifying drug-drug interactions, predicting possible adverse drug reactions, monitor pharmacokinetics, identify optimal drug dosages, and customize individualized treatment plans for patients.⁹ Moreover, AI can analyze patient data and identify the need for intervention or medication adjustments leading to improved therapy management. Therefore, pharmacists can minimize adverse events, improve therapeutic outcomes, and satisfy their patients.¹⁰

Different forms of AI techniques are used to provide such technology. Firstly, the rapidly growing, machine learning (ML).¹¹ Another progressing technique is natural language processing (NLP)¹² and finally, data mining where an advanced algorithm is used to analyze patient data, personalize treatment plans, and identify medication-related errors. Therefore, clinical and retail pharmacists can make evidence-based interventions and recommendations, and enhance safety and quality of patient care through the AI-driven decision support system.¹³

Incorporating AI into pharmacy practice offers the potential to increase efficiency and improve healthcare delivery. AI-powered technologies have the potential to automate drug administration operations, decreasing human errors and increasing workflow efficiency.¹⁴ Automation and robotics can manage pharmaceutical inventories, ensure exact stock levels, and decrease waste.¹⁵ These advancements not only alleviate the workload of pharmacists but also enable them to prioritize providing patient care including counseling and enhancing patient adherence to treatment. However, other than the potential benefits, it is critical to recognize the limitations

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and challenges connected with the implementation of AI in pharmacy practice. To ensure the appropriate and successful use of AI technologies, ethical concerns, privacy protection, and regulatory compliance must be addressed.⁹ This comprehensive review article contributes to the existing articles regarding the use of AI technology in pharmacy practice and aims to address the wide range of AI applications in pharmacy practice and focus on its impact on pharmacists and patient-centered care.

OBJECTIVE

This comprehensive review article provides a thorough analysis of the application of AI in pharmacy practice, applicable to both clinical and retail pharmacists. With a unique focus on medication management, pharmacy workflow, and patient care. It goes beyond a surface-level examination by going further and providing examples from previous studies to illustrate the use and impact of AI on pharmacy practice focusing on medication management, pharmacist workflow, and patient care, in addition to the subsequent influence on patient health outcomes. Moreover, the article takes a critical approach by identifying and discussing the barriers and ethical issues that arise with the integration of AI in the healthcare profession and highlighting its future direction in pharmacy practice. This article offers valuable insights into the evolving landscape of medication management, pharmacist workflow, and patient care in the pharmacy practice using AI-based technology. Through its comprehensive coverage and unique analysis, this research article serves as a significant resource for pharmacists, healthcare professionals, researchers, and policymakers seeking to understand and harness the potential of AI in optimizing pharmacy practice and improving patient care.

METHODOLOGY

Comprehensive research was employed to evaluate relevant publications within the scope of AI in pharmacy practice. The search strategy incorporated keywords related to "Artificial intelligence in pharmacy practice", "Artificial intelligence in healthcare", "Artificial intelligence and medication management", "pharmacy workflow", "patient care", "patient counseling", "patient adherence", "ethical issues", and "pharmacists' education". Extensive literature searches were conducted across trusted databases, including Google Scholar, PubMed, and SCOPUS. Furthermore, specific AI software and applications were identified through Google searches and by referencing the owners' websites for further investigation. Only references indexed between July 2015 and July 2023 were considered to ensure the inclusion of recent and up-to-date information.

Medication management

The impact of medication errors on patient well-being cannot be overstated. Each year, a huge number of individuals suffer tragic consequences, including loss of life and unreported adverse reactions or complications. These errors create a heavy financial burden, exceeding \$40 billion annually and

affecting millions of patients. However, the consequences extend far beyond the circle of finances. Patients endure not only physical pain and suffering but also face emotional distress and psychological trauma. Furthermore, medication errors undermine the trust that patients place in the healthcare system, leading to decreased satisfaction with their overall care experience. Recognizing the seriousness of these consequences needs a concerted effort to enhance medication safety, promote attentive practices, and ensure patient-centered care. By addressing these challenges directly, healthcare professionals can work towards a future where medication errors are minimized, patient well-being is prioritized, and trust in the healthcare system is restored.¹⁶⁻¹⁸

Incorrect patient identification and medication administration are two of the most prevalent medication errors. These errors include incorrect dosing, improper medication selection, and errors in monitoring patients with liver or kidney disease or allergies. Medication management is critical to avoid these errors, and pharmacists are at the forefront of developing and implementing safety improvements.^{6,7} Artificial intelligence (AI) can serve as a valuable tool to aid pharmacists in enhancing patient safety and minimizing errors.¹⁹ Some of the potential uses of AI in aiding pharmacists in maximizing medication management are as follows:

Optimized medication selection

Optimized medicine selection is a critical process that aims to ensure the best possible treatment outcome for individual patients. It involves a comprehensive evaluation of numerous factors, including the patient's medical conditions, symptoms, medical history, genetic factors, demographic information, potential drug interactions, and possible side effects.²⁰ Pharmacists analyze all these data and then can make decisions to minimize the risks associated with medication and maximize therapeutic benefits. This individualized approach acknowledges that patients have different responses to the medications due to factors such as genetic variations, pre-existing conditions, and polypharmacy.²¹ Pharmacists are part of this process because they are medication expertise and prevent medication errors by ensuring the right drug, frequency, dose, and dosage form.²² So how can Artificial intelligence aid pharmacists in optimizing medicine? AI-based systems can provide pharmacists with advanced decision-support tools. These tools analyze vast amounts of patient data from various sources, including electronic health records (EHR), genomic sequencing, medical reports, and lifestyle information.²³⁻²⁵ The more comprehensive and diverse the data, the better AI can understand individual patients' unique characteristics and medication needs. Pharmacists can take advantage of AI models to generate predictions and recommendations made specifically for individual patients. These models know historical patients' data, treatment outcomes, and medical knowledge to outlook the disease progression, treatment response, and potential adverse effects.²⁶⁻²⁷ One area where AI plays a significant role in pharmacogenomics is where pharmacists utilize a patient's genetic information to optimize their response to medication therapy. AI assists in interpreting



pharmacogenomic data, identifying how an individual's genetic makeup may influence their response to specific medications.²⁸ By considering these results of the genetic factors, AI systems provide insights into optimal medication selection and dosing adjustments, personalized to a patient's genetic profile.²⁹ Moreover, another feature that AI can provide is facilitating the screening of phenotype drug compounds, enabling the prediction of how individual patients will respond to specific medications. By analyzing patient data and integrating it with specific to drug information, AI models estimate the likelihood of therapeutic success and identify patients who may be at a higher risk of adverse reactions.³⁰⁻³² In some cases, where no previous predictions of treatments exist, personalized drug screening strategies can be employed using biopsies or biomaterials obtained from patients. This approach mostly performed in a hospital setting, as suggested by Kodack et al. in the context of cancer, helps ensure the molecular structure of the drug produced has favorable properties inside the body.³³ CURATE.AI is a noteworthy example of AI software, it can optimize real-time treatment, allowing for personalized adjustments that can lead to improved outcomes, identifying patterns, and refining treatment strategies accordingly. Initially, the platform analyzes the patients' data such as genetic factors, environmental factors, and lifestyle, to establish a baseline profile and understand the individual response to treatments. As the patient progresses through the treatment plan, CURATE.AI continuously adapts the plan in response to real-time feedback, adjusting dosage, timing, or combination of therapies as necessary. It aims to provide personalized and dynamic treatment plans that are tailored to each patient's unique characteristics and evolving needs, leading to improved

treatment efficacy, minimized side effects, and ultimately provide better patient care.¹⁸⁻³⁴ (Figure 1)

Predicting Adverse drug events, Adverse drug reactions, and Drug Interactions

Adverse drug events, adverse drug reactions, and drug interactions are medication errors that pose substantial risks to patients and are major concerns in the field of healthcare.³⁵ However, the application of AI technology offers a promising solution to enhance the prediction and management of these reactions. In a recent study conducted by Westerman and his colleagues in 2022, machine learning techniques and the U.S. FDA Adverse event reporting system (FAERS) database were employed to improve the identification of adverse events associated with new drug combinations. The researchers identified patterns linking drugs to specific side effects, by utilizing dimensional reduction and a convolutional neural network algorithm, these patterns were then encoded into a compressed representation known as "latent space", enabling simplified analysis and interpretation of adverse event profiles.^{36,37} AI algorithms, including deep learning and convolutional neural networking, can process vast amounts of data and identify tricky associations between drugs and adverse events, adverse reactions, and drug interactions.³⁸ These predictions happen by analyzing diverse sources of information, such as electronic health records, drug databases, clinical trial data, adverse events, and adverse reaction reporting systems.³⁹ AI algorithms can uncover relationships and risk factors of medications that may not be visible to human experts.

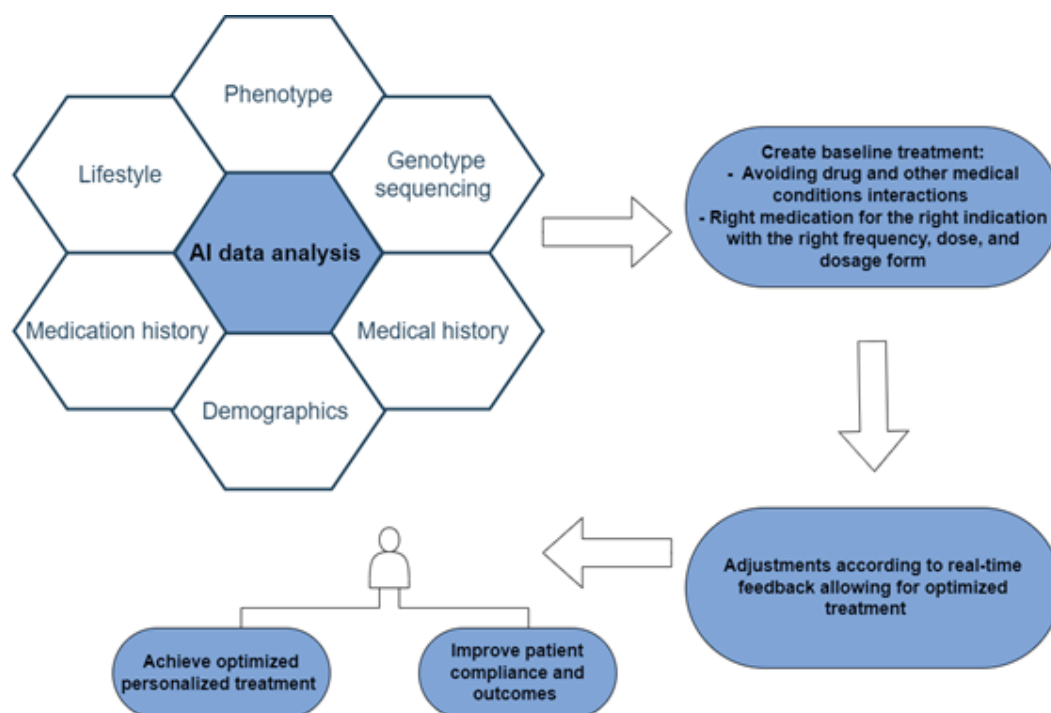


Figure 1: Process of Medication management using optimized medication selection by Artificial Intelligence [18, 21-25, 34]

A notable example of AI's application in predicting adverse drug reactions comes from a study conducted by Stanford researchers in 2018. They developed an AI deep learning technology that successfully identified numerous drug interactions and associated complications. This study demonstrated the potential of AI to accurately predict adverse drug reactions, drug interactions, and their complications.⁴⁰

Furthermore, AI plays a crucial role in identifying and managing drug interactions. AI algorithms can screen for potential drug interactions, encompassing both drug-drug interactions, and drug-disease interactions, and provide alerts to the healthcare provider and patients. For example, when a patient has been prescribed a new medication while already taking another for a different medical condition, AI can analyze the potential interactions between the drugs and alert pharmacists, offering recommendations on adjusting dosages or suggesting alternative medications. In addition to that, Artificial intelligence can screen for drug-disease interactions, identify medications that may worsen pre-existing conditions, and provide appropriate alerts and suggestions.⁴¹⁻⁴³ The mentioned implications of AI in predicting Adverse drug events, adverse drug reactions, and drug interactions have the potential to aid pharmacists in preventing medication errors to enhance patient safety and improve medication management. The AI models continuously learn and adapt as new data becomes available, enhancing the accuracy and reliability of the predictions over time.⁴⁴

Pharmacy workflow

In the profession of modern pharmacy, there is a notable shift towards prioritizing patient-centered care.^{45,46} However, this raises the question of what happens to the other essential tasks traditionally carried out by pharmacists. These tasks include verifying prescriptions, performing doublechecks to prevent errors, managing inventory, dispensing medications, patient counseling and education. The heavy workload placed on pharmacists compromises their ability to deliver optimal patient-centered care. To address this challenge, the integration of AI technology can alleviate pharmacists' technical responsibilities, allowing them to focus on providing personalized care to patients.^{6,47}

Robotic dispensing integrated with AI technology

Pharmacy dispensing robotics is one of the most significant technologies that play a prominent role in the advancement of hospital pharmacy systems.⁴⁸ Pharmacists operate under extreme pressure and have countless workloads, which can lead to dispensing errors, such as sound-alike and look-alike medications that threaten the patient well-being.⁴⁷ The need for robotic-assisted pharmacies is arising from here to distribute drugs to reduce such human errors, as robots can provide accurate dispensing and enhance patient safety.⁴⁸ In Australia, an AI-integrated dispensing robotic called Fred AID (Artificial intelligence directions) was introduced in 2021. This system assists pharmacists in reducing the time spent on repetitive tasks such as entering medication directions, ultimately increasing pharmacist time on patient care, hence

increasing patient safety.⁴⁹ Emirates health services also introduced the robotic pharmacy in 2022, which operates autonomously through AI-integrated technology. This advanced system can identify and locate thousands of different medications, enhancing the efficiency and effectiveness of the dispensing process.⁵⁰ One notable example of a hospital robot is the "Drug Station", which was developed by Yuyama Co., Ltd.,. It is specifically designed to store large quantities of single-unit packages, accommodating approximately 1,200 units of various oral medications. The robot facilitates the retrieval of prescribed medicines based on instructions on the screen, by connecting to the hospital's computerized order entry, then by utilizing prescription data from the computerized order entry system, the robot transfers the preparation of the medication. Furthermore, to verify the quantities of the medications, the robot employs electronic scales or built-in cameras.⁵¹ Omnicell, a leading provider of pharmacy automation solutions, has expanded its reach to include retail pharmacy settings in addition to hospitals. Their robotic systems offer advanced storage capabilities tailored for chaotic storage environments. In these environments, medication packs are strategically placed on shelves to optimize space utilization, benefiting hospitals with extensive formularies. Alternatively, the channel-fed dispensing method allows for faster picking speeds by dedicating specific channels to different types of drugs. However, channel-fed storage requires careful sizing of channels to accommodate varying pack sizes, which can be a challenge. The Medimat system represents the next generation of pharmacy automation by combining both chaotic and channel-fed storage features in a single system. This innovative approach ensures the fastest dispensing speed for frequently used drug lines, while still providing the flexibility to store other drug lines in the chaotic storage unit. The Medimat system serves as a compact storage warehouse and dispensing unit, incorporating a semi-automated filing system for enhanced efficiency.^{14,52} These robotic systems when integrated with AI technology, can aid in preventing errors, increasing patient safety, and easing pharmacist workflow.

Inventory management

AI technology has the potential to transform inventory management practices within the field of pharmacy, offering a range of benefits and efficiencies. One significant advantage offered by AI in inventory management is the ability to predict future medication needs accurately.⁵³ Pharmacists can forecast the demand for specific medications based on historical sales data, patient demographics, and other relevant factors. This predictive capability empowers pharmacists to optimize their inventory levels, ensuring they have the right medications in stock at the right time while avoiding overstocking or out-of-stock situations. Moreover, AI-based systems can automate the replenishment process. Real-time monitoring of inventory levels enables the automatic generation of purchase orders when the stock falls below a threshold that has been set. This automated approach eliminates the need for manual intervention, expediting the procurement process and ensuring timely restocking of essential medications.⁵⁴⁻⁵⁶ AI is also important in supply chain optimization, it can optimize



drug distribution and delivery by analyzing massive volumes of supply chain data, such as lead times, supplier performance, and transportation logistics. This not only cuts prices but also wastes and improves overall operational efficiency.^{57,58} One notable example of AI-powered inventory management software is LEAFIO. This system offers a range of features to facilitate effective inventory control. It allows pharmacists to replenish, track and match substitute products when new medication modification becomes available. Not only that, but it can also predict demand for new products by analyzing sales history, preventing losses due to overstocking. LEAFIO helps in maintaining an adequate inventory buffer by considering shelf life, availability, and delivery time. In situations where certain medications are unavailable, an intelligent selection of substitute products ensures patient satisfaction and avoids lost sales. An important feature in inventory management is expiration date management. AI systems can track and monitor the expiration dates of medication, altering pharmacists' advances when a medication is near expiration. This approach enables pharmacies to minimize the risk of dispensing expired medications to patients and thus ensuring their safety. Furthermore, AI systems contribute to accurate demand estimation and analyzing drug product ranges to identify slow-moving products, this capability prevents unnecessary accumulation of slow-moving products and optimizes the availability of high-demand products.⁵⁹

Prescription verification

Pharmacists have the responsibility of verifying prescriptions provided by patients and detecting any associated errors. However, they are also susceptible to making mistakes, such as misinterpreting the prescriber's handwriting or overlooking medication errors like those discussed in this article, such as incorrect dosage, frequency, or indications for the wrong patient. In a 2022 study, an AI-powered technique called signature verification was employed to investigate features that significantly enhance the accuracy of dispensing the correct medication based on the prescription. The dataset used in the study included 24 medicine names from 2 users, and the results demonstrated an improved accuracy ranging from 38.5% to 84% across 9 users.⁶⁰ MedAware, a healthcare solutions provider utilizing AI technology, has developed a robust system that leverages algorithms to improve patient safety. This system generates real-time alerts for healthcare providers whenever a potential prescription error is detected. These alerts seamlessly integrate into the workflow, prescribing system, and electronic health record (EHR). Each alert precisely highlights the specific error and offers actionable information and recommendations to promptly address the issue. One significant aspect of MedAware is its continuous refinement of algorithms through ongoing learning and adaptation. As the system processes and analyzes more prescriptions, it ensures that the system evolves and adjusts to the ever-changing landscape of prescription practices.⁶¹

Patient care

Pharmacy professionals go beyond their traditional role in managing pharmacies, and play a crucial part in patient-centered

care, particularly in the management of chronic diseases they serve as coaches, guiding patients on adopting healthy eating styles, helping them quit smoking, and addressing active lifestyles.⁶² Pharmacists provide extended services, educate patients, and promote treatment adherence. The major barriers were the lack of time from the pharmacists due to the workflow.⁶³ Meanwhile, the integration of AI technology offers pharmacists a comprehensive understanding of each patient's unique needs, enabling personalized interventions.⁶⁴ Artificial technology can evaluate massive volumes of data and actively engage patients by making individualized recommendations and therapies.²⁴ This enables individuals to actively participate in their health management, resulting in improved adherence and better health outcomes. The combination of pharmacy experience and AI capabilities allows pharmacist services to be expanded, making them more individualized, efficient, and accessible.

Lifestyle management and counseling

Artificial intelligence offers potential benefits in areas such as behavioral coaching, personal nutrition intervention, physical activity recommendations, and patient education.⁶⁵ One significant area where AI has shown promise is personalized diet planning. Research has demonstrated that individuals are more likely to adhere to a diet plan for a longer period if it is tailored to their specific needs and preferences, by incorporating factors such as food of preference, cultural background, and lifestyle habits.⁶⁶ This personalized approach allows healthcare professionals to identify potential nutrient deficiencies that may contribute to patients' health issues. For instance, an AI algorithm can recognize a patient with a history of anemia and recommend a plant-based diet that would benefit from incorporating more iron-rich foods and supplements.⁶⁷ Moreover, Artificial intelligence can go further and identify potential intolerance, this enables the creation of diet plans that avoid triggers and promote better health outcomes for individuals.⁶⁷ This level of precision in diet guidance can help prevent and manage chronic diseases and improve overall health.⁶⁸ AI has demonstrated its potential to assist individuals in quitting smoking. For example, Persuasive Communication Tailoring and Quit Coach are AI-powered platforms that have successfully offered tailored therapies, resulting in better outcomes compared to traditional interventions. These platforms send individualized messages to individuals attempting to quit smoking, help set an end date for smoking, provide support during moments of cravings, and assist in navigating situations where the patient used to smoke. Not only that, but these innovative apps utilize interactive conversation with virtual characters to raise awareness about the harmful consequences of tobacco use.^{69,70} Breast cancer was another condition where AI served as a valuable resource for the empowerment of patients and their loved ones. "Vik" is a chatbot, where it aimed in breast cancer to enhance patient outcomes through sending personalized text messages, Vik provides treatment reminders, educational content, and relevant medical information related to the disease.⁷¹ ChatGPT, a similar software, plays a significant role in providing valuable assistance and vital information to patients, including guidance



on medication usage and information about associated side effects. This is especially relevant for patients with mental illnesses who may find it difficult to engage in face-to-face interactions. The accessibility offered by AI-based systems encourages patients to actively participate in therapy and empowers them to seek the assistance they need.⁷²⁻⁷⁴ Moreover, these AI-driven systems use the power of machine learning to deliver personalized support, thereby increasing the likelihood of effectively managing individuals' specific conditions. This technology has massive potential in assisting pharmacists in providing personalized extended services and counseling to patients. By benefiting from this advanced technology, not only does patient adherence improve significantly, but overall health outcomes are also greatly enhanced.

Monitoring Adherence

In non-adherence patients, the pharmacist's role is to implement various interventions to improve adherence, including additional counseling sessions, adherence aids, and personalized reminder systems.⁷⁵ Artificial intelligence plays a crucial role in enhancing medication adherence. For instance, Labovitz et al. developed an AI-generated smartphone app that uses a neural network computer vision algorithm to visually identify patients, and medication, and confirm ingestion. The app provides medication reminders and instructions on dosing. It was proven to work on stroke patients and increased their adherence to anticoagulants.⁷⁶ Similarly, Bain et al. evaluated an AI platform based on a smartphone application, it utilizes facial recognition, computer vision, and software algorithms to assess adherence in patients with schizophrenia and cognitive impairment. Through the AI platform, it was demonstrated increased adherence rates compared to the control group.⁷⁷ These studies emphasize the potential of Artificial intelligence in rapidly detecting nonadherence and predicting future non-adherence. Another approach using AI to enhance patient adherence is remote patient monitoring (RPM), this system utilizes virtual assistants to send smart text-based communications to patients, reminding them to take readings and providing support and education.⁷⁸ Several apps such as AiCure employ advanced technology such as the use of live footage to observe patients taking their medication correctly. Smart packaging such as a smart pillbox, can alert the patient when to take the medications using sounds and lights, and also track when medication is taken out of packaging.⁷⁹ Wearable devices have been developed to gather individuals' personal health and exercise data, with the ability to transmit this information in real-time to healthcare professionals. These devices serve as remote tools for monitoring and enabling timely interventions. For instance, a wearable patch affixed to the skin can detect whether the patient ingested the pills or not and at what time, by sensing the presence of a pill sensor. Additionally, these wearables can do more than just detect actions, they can also alert patients to abnormal heart rates, and lack of movement, and remind them to take their medications. Such wearable technologies play a crucial role in improving patient care by promoting medication adherence and offering valuable insights into activity levels and medication usage.^{78,80,81} (Figure 2)

Barriers to AI in pharmacy practice

The integration of Artificial intelligence into the pharmacy practice has undeniable positive impacts. However, it is important to acknowledge and face the barriers and challenges associated with this implementation to prevent potential difficulties and future complications. Unlike the authentic human connection between pharmacists and patients, robots lack the capacity for sympathy and empathy, which are essential elements of humane care, which cannot be provided by AI technologies. The interaction between pharmacists and patients provides better understanding, ultimately leading to improved care and increased patient compliance with treatment regimens.⁸² Moreover, these advanced technologies have limitations in terms of their capacity for human-like creativity. They rely heavily on existing data and struggle to address unanticipated issues, which can potentially lead to misleading reports.⁸³

AI systems must be meticulously programmed to minimize the occurrence of errors, for that reason the cost associated with implementing AI technology are substantial, encompassing initial investments, malignance expenses, and regular updates. Pharmacists encounter challenges related to their familiarity with these technologies and their ability to effectively navigate AI systems and robots, therefore, adequate, and extensive training is necessary for pharmacists to become proficient in operating these systems.⁴⁸ In addition to technical issues, ethical considerations must be considered. These include addressing algorithmic biases and obtaining informed consent from patients for the usage of their data to ensure the transparency and safety of AI systems. These ethical considerations play a significant role in maximizing the benefits of AI while upholding patient rights, well-being, and trust in the healthcare system.⁸²

Recommendations to overcome the barriers

Some of the barriers associated with Artificial Intelligence (AI) in healthcare can be overcome to fully utilize its potential. Firstly, AI systems should undergo rigorous testing to ensure the accuracy of information and results, thereby avoiding potential medical errors and fatalities. Secondly, healthcare organizations are strongly encouraged to obtain explicit consent for data processing, invest in enhancing privacy measures to protect sensitive data, and implement systems for timely breach notifications. Regarding AI biases, it is essential to conduct regular checkups and monitoring to ensure the reliability of these tools, while also striving to build a more diverse and representative collection of data. Furthermore, providing comprehensive training sessions for pharmacists on how to effectively use AI systems and leverage their benefits is crucial. By addressing these challenges and adopting proactive measures, the healthcare industry can harness the full potential of AI, leading to improved patient care and outcomes.^{84,85}

Conclusions and future perspective

The integration of AI in pharmacy practice presents a transformative outlook for healthcare delivery. Through the continuous advancements in AI algorithms, machine learning, and data analytics, pharmacists will gain access to



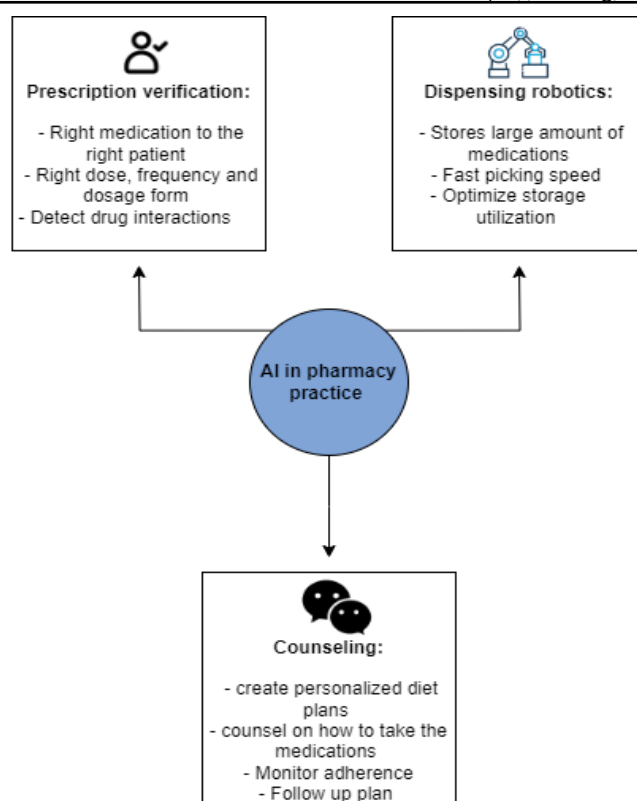


Figure 2: The use of Artificial intelligence (AI) in pharmacy practice [14, 40, 52, 60,61, 67,78-81]

extraordinary tools and resources that will enhance medication management, treatment optimization, and patient outcomes. Personalized medicine will be a reality, as AI algorithms analyze patient-specific data to customize treatment plans and predict individual responses to medications. AI-driven systems will efficiently organize pharmacy workflows, automating repetitive tasks and freeing up pharmacists' time for patient care and counseling. Furthermore, AI-enabled systems will significantly enhance medication safety by identifying potential drug interactions, adverse effects, and medication errors. However, to fully utilize the potential of AI integration in pharmacy, important challenges such as ethical considerations, data privacy, and ongoing training and education for pharmacists need to be addressed. While AI technology has the potential to enhance efficiency, it cannot replace the indispensable role of pharmacists in providing sympathy and empathy to patients, and limited pharmacist-patient interaction due to the integration of such technologies may raise concerns among patients, emphasizing the ongoing importance of maintaining human connection and trust in healthcare services. The future of AI in pharmacy holds immense promise in transforming healthcare delivery and elevating patient care to unprecedented levels, provided that the challenges are effectively managed, and the human touch is preserved. Lastly, it is important to explore pharmacists' and patient perspectives and experiences with AI-based pharmacy services to address concerns, enhance patient satisfaction, and promote engagement with these

technologies.

DECLARATIONS

ETHICS APPROVAL AND CONSENT TO PARTICIPATE: Not applicable.

CONSENT FOR PUBLICATION: Not applicable

AVAILABILITY OF DATA AND MATERIALS: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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References

1. What is artificial intelligence (AI)? - AI definition and how it works. Enterprise AI n.d. <https://www.techtarget.com/searchenterpriseai/definition/AI-Artificial-Intelligence> (accessed May 26, 2023)
2. Nelson SD, Walsh CG, Olsen CA, et al. Demystifying artificial intelligence in pharmacy. *American Journal of Health-System Pharmacy*. 2020;77:1556-70. <https://doi.org/10.1093/ajhp/zxaa218>
3. Bajwa J, Munir U, Nori A, et al. Artificial intelligence in healthcare: transforming the practice of medicine. *Future Healthc J*. 2021;8:e188-94. <https://doi.org/10.7861/fhj.2021-0095>
4. Mijwil M, K Faieq A, Al-Mistarehi A-H. The Significance of Digitalisation and Artificial Intelligence in The Healthcare Sector: A Review. *Asian Journal of Pharmacy Nursing and Medical Sciences* 2022;10:25-32. <https://doi.org/10.24203/ajpnms.v10i3.7065>
5. Pharmacist Role in Patient Safety 2020.
6. Tariq RA, Vashisht R, Sinha A, et al. Medication Dispensing Errors And Prevention. StatPearls, Treasure Island (FL): StatPearls Publishing; 2023.
7. The Pharmacist's Role in Medication Safety 2018.
8. Raza MA, Aziz S, Noreen M, et al. Artificial Intelligence (AI) in Pharmacy: An Overview of Innovations. *Innov Pharm*. 2022;13:1. <https://doi.org/10.24926/iip.v13i2.4839>
9. Mintz Y, Brodie R. Introduction to artificial intelligence in medicine. *Minimally Invasive Therapy & Allied Technologies*. 2019;28:73-81. <https://doi.org/10.1080/13645706.2019.1575882>
10. Babel A, Taneja R, Mondello Malvestiti F, et al. Artificial Intelligence Solutions to Increase Medication Adherence in Patients With Non-communicable Diseases. *Front Digit Health*. 2021;3:669869. <https://doi.org/10.3389/fdgh.2021.669869>
11. Mijwil MM, Aggarwal K. A diagnostic testing for people with appendicitis using machine learning techniques. *Multimed Tools Appl*. 2022;81:7011-23. <https://doi.org/10.1007/s11042-022-11939-8>
12. van der Lee M, Swen JJ. Artificial intelligence in pharmacology research and practice. *Clin Transl Sci*. 2022;16:31-6. <https://doi.org/10.1111/cts.13431>
13. Wu W-T, Li Y-J, Feng A-Z, et al. Data mining in clinical big data: the frequently used databases, steps, and methodological models. *Military Medical Research*. 2021;8:44. <https://doi.org/10.1186/s40779-021-00338-z>
14. Medimat - Pharmacy Robotic Medication Dispensing Systems n.d. <https://www.omnicell.co.uk/products/medimat-next-generation-robot-for-retail-pharmacy> (accessed June 15, 2023).
15. anna.cherniavska. What Is Pharmacy Automation And Why Is It Necessary? Chudovo 2023. <https://chudovo.com/what-is-pharmacy-automation-and-why-is-it-necessary/> (accessed May 27, 2023).
16. Whittaker CF, Miklich MA, Patel RS, et al. Medication Safety Principles and Practice in CKD. *Clin J Am Soc Nephrol*. 2018;13:1738-46. <https://doi.org/10.2215/CJN.00580118>
17. Medication Errors: Why We Must Look Beyond the "Five Rights" n.d. <https://www.performancehealthus.com/blog/medication-errors-why-we-must-look-beyond-five-rights> (accessed June 9, 2023).
18. da Silva BA, Krishnamurthy M. The alarming reality of medication error: a patient case and review of Pennsylvania and National data. *Journal of Community Hospital Internal Medicine Perspectives*. 2016;6:31758. <https://doi.org/10.3402/jchimp.v6.31758>
19. The future of pharmacy: How AI is revolutionizing the industry. *Intelligent Pharmacy*. 2023;1:32-40. <https://doi.org/10.1016/j.ipha.2023.04.008>
20. Maxwell SR. Rational prescribing: the principles of drug selection. *Clin Med (Lond)*. 2016; 16:459-64. <https://doi.org/10.7861/clinmedicine.16-5-459>
21. Watanabe JH. Pharmacist-directed care to optimize medication use: a healthcare imperative in the United States. *Expert Review of Pharmacoeconomics & Outcomes Research*. 2020; 20:419-21. <https://doi.org/10.1080/14737167.2020.1820865>
22. Schork NJ. ARTIFICIAL INTELLIGENCE AND PERSONALIZED MEDICINE. *Cancer Treat Res*. 2019;178:265-83. https://doi.org/10.1007/978-3-030-16391-4_11
23. Deng J, Hartung T, Capobianco E, et al. Editorial: Artificial Intelligence for Precision Medicine. *Frontiers in Artificial Intelligence* 2022;4.
24. Johnson KB, Wei W, Weeraratne D, et al. Precision Medicine, AI, and the Future of Personalized Health Care. *Clin Transl Sci*. 2021;14:86-93. <https://doi.org/10.1111/cts.12884>
25. Acosta JN, Falcone GJ, Rajpurkar P, et al. Multimodal biomedical AI. *Nat Med*. 2022; 28:1773-84. <https://doi.org/10.1038/s41591-022-01981-2>
26. Majnarić LT, Babić F, O'Sullivan S, et al. AI and Big Data in Healthcare: Towards a More Comprehensive Research Framework for Multimorbidity. *J Clin Med*. 2021;10:766. <https://doi.org/10.3390/jcm10040766>
27. Artificial intelligence and machine learning in precision and genomic medicine - PMC n.d. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9198206/> (accessed June 3, 2023).
28. Medication Management n.d. <https://www.pharmacist.com/Practice/Patient-Care-Services/Medication-Management/> (accessed June 9, 2023).



29. Schork NJ. ARTIFICIAL INTELLIGENCE AND PERSONALIZED MEDICINE. *Cancer Treat Res.* 2019;178:265-83. https://doi.org/10.1007/978-3-030-16391-4_11
30. He D, Liu Q, Wu Y, et al. A context-aware deconfounding autoencoder for robust prediction of personalized clinical drug response from cell-line compound screening. *Nat Mach Intell.* 2022;4:879-92. <https://doi.org/10.1038/s42256-022-00541-0>
31. A Deep Learning Framework for Predicting Response to Therapy in Cancer - ScienceDirect n.d. <https://www.sciencedirect.com/science/article/pii/S2211124719314883> (accessed June 3, 2023).
32. Using deep learning to model the hierarchical structure and function of a cell | *Nature Methods* n.d. <https://www.nature.com/articles/nmeth.4627?ref=https://githubhelp.com> (accessed June 2, 2023).
33. Primary Patient-Derived Cancer Cells and Their Potential for Personalized Cancer Patient Care - ScienceDirect n.d. <https://www.sciencedirect.com/science/article/pii/S2211124717317035> (accessed June 2, 2023).
34. Blasiak A, Khong J, Kee T. CURATE.AI: Optimizing Personalized Medicine with Artificial Intelligence. *SLAS Technology.* 2020;25:95-105. <https://doi.org/10.1177/2472630319890316>
35. Medication Misadventures I: Adverse Drug Reactions. McGraw Hill Medical n.d. <https://accesspharmacy.mhmedical.com/content.aspx?sectionid=177200213&bookid=2275> (accessed June 10, 2023).
36. Staff TAP. AI Model May Help Predict Adverse Events From New Drug Combinations - The ASCO Post n.d. <https://ascopost.com/news/april-2022/ai-model-may-help-predict-adverse-events-from-new-drug-combinations/> (accessed June 10, 2023).
37. Masumshah R, Aghdam R, Eslahchi C. A neural network-based method for polypharmacy side effects prediction. *BMC Bioinformatics.* 2021;22:385. <https://doi.org/10.1186/s12859-021-04298-y>
38. Mohsen A, Tripathi LP, Mizuguchi K. Deep Learning Prediction of Adverse Drug Reactions in Drug Discovery Using Open TG-GATEs and FAERS Databases. *Frontiers in Drug Discovery* 2021;1.
39. Choudhury O, Park Y, Salonidis T, et al. Predicting Adverse Drug Reactions on Distributed Health Data using Federated Learning. *AMIA Annu Symp Proc.* 2020;2019:313-22. <http://www.ncbi.nlm.nih.gov/pmc/articles/pmc7153050/>
40. University S. AI predicts drug pair side effects. *Stanford News* 2018. <https://news.stanford.edu/2018/07/10/ai-predicts-drug-pair-side-effects/> (accessed June 10, 2023).
41. Zhang Q, Li S, Chen F, et al. Targeted delivery strategy: A beneficial partner for emerging senotherapy. *Biomedicine & Pharmacotherapy.* 2022;155:113737. <https://doi.org/10.1016/j.biopha.2022.113737>
42. IT-based reminders for medication adherence: systematic review, taxonomy, framework and research directions: *European Journal of Information Systems: Vol 29, No 1* n.d. <https://www.tandfonline.com/doi/abs/10.1080/0960085X.2019.1701956> (accessed June 2, 2023).
43. Hung TNK, Le NQK, Le NH, et al. An AI-based Prediction Model for Drug-drug Interactions in Osteoporosis and Paget's Diseases from SMILES. *Mol Inform.* 2022;41:e2100264. <https://doi.org/10.1002/minf.202100264>
44. AI models can now continually learn from new data on intelligent edge devices like smartphones and sensors. *ScienceDaily* n.d. <https://www.sciencedaily.com/releases/2022/10/221004134359.htm> (accessed June 10, 2023).
45. Rasheed MK, Alqasoumi A, Hasan SS, et al. The community pharmacy practice change towards patient-centered care in Saudi Arabia: a qualitative perspective. *Journal of Pharmaceutical Policy and Practice.* 2020;13:59. <https://doi.org/10.1186/s40545-020-00267-7>
46. Gregório J, Cavaco A. The pharmacist's guide to the future: Are we there yet? *Research in Social and Administrative Pharmacy.* 2021;17:795-8. <https://doi.org/10.1016/j.sapharm.2020.05.029>
47. Applied Mathematics for Pharmaceutical Problems Using Robotics as Assistive Tools for Learning: A Comprehensive Review | Singhai | JTAM (Jurnal Teori dan Aplikasi Matematika) n.d. <https://journal.ummat.ac.id/index.php/jtam/article/view/4720> (accessed June 3, 2023).
48. Alahmari AR, Alrabghi KK, Dighriri IM, et al. An Overview of the Current State and Perspectives of Pharmacy Robot and Medication Dispensing Technology. *Cureus.* 2022;14. <https://doi.org/10.7759/cureus.28642>
49. Latest AI-powered pharmacy dispensing platform launched in Australia. *MobiHealthNews* 2021. <https://www.mobihealthnews.com/news/anz/latest-ai-powered-pharmacy-dispensing-platform-launched-australia> (accessed June 15, 2023).
50. Internet F. Emirates Health Services Adds Four Robotic Pharmacies and Smart Drug Self-Dispensing Systems. *Emirates Health Services - UAE* 2022. <https://www.ehs.gov.ae/en/media-center/news/emirates-health-services-adds-four-robotic-pharmacies-and-smart-drug-self-dispensing-systems> (accessed June 15, 2023).
51. Takase T, Masumoto N, Shibatani N, et al. Evaluating the safety and efficiency of robotic dispensing systems. *Journal of Pharmaceutical Health Care and Sciences.* 2022;8:24. <https://doi.org/10.1186/s40780-022-00255-w>
52. Kent C. Robotic drug dispensing: the pharmacy goes digital. *Pharmaceutical Technology* 2021. <https://www.pharmaceutical-technology.com/features/robotic-drug-dispensing-digital-pharmacy/> (accessed June 15, 2023).
53. Musanga - A Predictive Analytics Model for Pharmaceutical In.pdf n.d.
54. Otto Group Enters Strategic Partnership with Covariant to power its Logistics Network with AI Robotics n.d. <https://www.ottogroup.com/en/medien/newsroom/meldungen/otto-group-enters-strategic-partnership-with-covariant-to-power-its-logistics-network-with-ai-robotics.php> (accessed June 16, 2023).
55. AI Inventory Management: 7 Ways Artificial Intelligence Can Enhance Inventory Management. *Liquid Web* 2022. <https://www.liquidweb.com/blog/ai-inventory-management/> (accessed June 16, 2023).

56. How AI is improving medical inventory management 2022. <https://identimedical.com/how-ai-is-improving-medical-inventory-management/> (accessed June 16, 2023).
57. Ginsberg B. The Role of AI in Optimizing Supply Chain Management in the Fashion Industry. *ApparelMagic* 2023. <https://apparelmagic.com/the-role-of-ai-in-optimizing-supply-chain-management-in-the-fashion-industry/> (accessed June 16, 2023).
58. Niranjana K, Narayana KS, Rao MVALN. Role of Artificial Intelligence in Logistics and Supply Chain. 2021 International Conference on Computer Communication and Informatics (ICCCI). 2021;1-3. <https://doi.org/10.1109/ICCCI50826.2021.9402625>
59. LEAFIO AI Retail Platform for Pharmacies n.d. <https://www.leafio.ai/solution-for-pharmacies/> (accessed June 16, 2023).
60. Rani S, Rehman AU, Yousaf B, et al. Recognition of Handwritten Medical Prescription Using Signature Verification Techniques. *Comput Math Methods Med*. 2022;2022:9297548. <https://doi.org/10.1155/2022/9297548>
61. MedAware - Using AI to eliminate prescription errors. Digital Innovation and Transformation n.d. <https://d3.harvard.edu/platform-digit/submission/medaware-using-ai-to-eliminate-prescription-errors/> - Google Search n.d. https://www.google.com/search?q=MedAware+%E2%80%93+Using+AI+to+eliminate+prescription+errors.+Digital+Innovation+and+Transformation+n.d.+https%3A%2F%2Fd3.harvard.edu%2Fplatform-digit%2Fsubmission%2Fmedaware-using-ai-to-eliminate-prescription-errors%2F+&sxsrf=AB5stBheu_N7keqS6fH53lh9IEoczJI0A%3A1688313215927&ei=f52hZISTOMarkdUP9MuJyAg&ved=0ahUKEwjEzoTssPD_AhXGVAQEhTICkQ4dUDCA8&uact=5&oq=MedAware+%E2%80%93+Using+AI+to+eliminate+prescription+errors.+Digital+Innovation+and+Transformation+n.d.+https%3A%2F%2Fd3.harvard.edu%2Fplatform-digit%2Fsubmission%2Fmedaware-using-ai-to-eliminate-prescription-errors%2F+&gs_lcp=Cgxn3Mt-d2l6LXNlcnAQA0oECEYAFAAWABgAgAcAB4AIABAIjBAJBAjBAA&scient=gws-wiz-serp (accessed July 2, 2023).
62. Litvak I, Nguyen K, Pezzino NC. Community pharmacists' perceptions on their role in counseling patients on lifestyle modifications. *Journal of the American Pharmacists Association*. 2022. <https://doi.org/10.1016/j.japh.2022.12.012>
63. Palaian S, Alomar M, Hassan N, et al. Opportunities for extended community pharmacy services in United Arab Emirates: perception, practice, perceived barriers and willingness among community pharmacists. *Journal of Pharmaceutical Policy and Practice*. 2022;15:24. <https://doi.org/10.1186/s40545-022-00418-y>
64. Frąckiewicz M. The Role of AI in Lifestyle Medicine: Promoting Health and Wellness. *TS2 SPACE* 2023. <https://ts2.space/en/the-role-of-ai-in-lifestyle-medicine-promoting-health-and-wellness/> (accessed June 4, 2023).
65. Maher CA, Davis CR, Curtis RG, et al. A Physical Activity and Diet Program Delivered by Artificially Intelligent Virtual Health Coach: Proof-of-Concept Study. *JMIR Mhealth Uhealth*. 2020;8:e17558. <https://doi.org/10.2196/17558>
66. Jarbøl DE, Larsen PV, Gyrd-Hansen D, et al. Determinants of preferences for lifestyle changes versus medication and beliefs in ability to maintain lifestyle changes. A population-based survey. *Preventive Medicine Reports*. 2017;6:66-73. <https://doi.org/10.1016/j.pmedr.2017.02.010>
67. Frąckiewicz M. Artificial Intelligence in Clinical Nutrition: Personalized Diet Plans for Health. *TS2 SPACE* 2023. <https://ts2.space/en/artificial-intelligence-in-clinical-nutrition-personalized-diet-plans-for-health/> (accessed June 18, 2023).
68. de Moraes Lopes MHB, Ferreira DD, Ferreira ACBH, et al. Chapter 20 - Use of artificial intelligence in precision nutrition and fitness. In: Barh D, editor. *Artificial Intelligence in Precision Health*, Academic Press. 2020;465-96. <https://doi.org/10.1016/B978-0-12-817133-2.00020-3>
69. QuitCoach > Home n.d. <http://www.quitcoach.org.au/> (accessed June 18, 2023).
70. Shete M, Shete A. Applied Artificial Intelligence for Tobacco Cessation in the Era of COVID-19: A Perspective. *Asian Pac J Cancer Prev*. 2022;23:2551-2. <https://doi.org/10.31557/APJCP.2022.23.8.2551>
71. Chaix B, Bibault J-E, Pienkowski A, et al. When Chatbots Meet Patients: One-Year Prospective Study of Conversations Between Patients With Breast Cancer and a Chatbot. *JMIR Cancer*. 2019;5:e12856. <https://doi.org/10.2196/12856>
72. Javid M, Haleem A, Singh RP. ChatGPT for healthcare services: An emerging stage for an innovative perspective. *BenchCouncil Transactions on Benchmarks, Standards and Evaluations*. 2023;3:100105. <https://doi.org/10.1016/j.tbench.2023.100105>
73. Xie Y, Seth I, Hunter-Smith DJ, Rozen WM, et al. Aesthetic Surgery Advice and Counseling from Artificial Intelligence: A Rhinoplasty Consultation with ChatGPT. *Aesth Plast Surg*. 2023. <https://doi.org/10.1007/s00266-023-03338-7>
74. Release P. D14.AI launches AI-driven patient education platform - DHealth n.d. <https://www.zawya.com/en/press-release/companies-news/d14ai-launches-ai-driven-patient-education-platform-dhealth-kzvx57bi> (accessed June 19, 2023).
75. Usherwood T. Encouraging adherence to long-term medication. *Aust Prescr*. 2017;40:147-50. <https://doi.org/10.18773/austprescr.2017.050>
76. Using Artificial Intelligence to Reduce the Risk of Nonadherence in Patients on Anticoagulation Therapy | *Stroke* n.d. <https://www.ahajournals.org/doi/full/10.1161/STROKEAHA.116.016281> (accessed June 2, 2023).
77. JMIR mHealth and uHealth - Use of a Novel Artificial Intelligence Platform on Mobile Devices to Assess Dosing Compliance in a Phase 2 Clinical Trial in Subjects With Schizophrenia n.d. <https://mhealth.jmir.org/2017/2/e18> (accessed June 2, 2023).
78. How AI-Enabled Remote Patient Monitoring Is Improving Patient Adherence and Outcomes. *Patient Safety & Quality Healthcare* 2022. <https://www.psqh.com/analysis/how-ai-enabled-remote-patient-monitoring-is-improving-patient-adherence-and-outcomes/> (accessed June 17, 2023).
79. Abdul Minaam DS, Abd-ELfatah M. Smart drugs:Improving healthcare using Smart Pill Box for Medicine Reminder and Monitoring System. *Future Computing and Informatics Journal*. 2018;3:443-56. <https://doi.org/10.1016/j.fcij.2018.11.008>
80. Quinn JP. AI in Pharmacy: How will it change things? 2022. <https://www.pharmacymentor.com/ai-change-pharmacy/> (accessed



June 4, 2023).

81. Wedlund L, Kvedar J. Wearables as a tool for measuring therapeutic adherence in behavioral health. *Npj Digit Med*. 2021;4:1-2. <https://doi.org/10.1038/s41746-021-00458-9>
82. Gerke S, Minssen T, Cohen G. Chapter 12 - Ethical and legal challenges of artificial intelligence-driven healthcare. In: Bohr A, Memarzadeh K, editors. *Artificial Intelligence in Healthcare*, Academic Press. 2020;295-336. <https://doi.org/10.1016/B978-0-12-818438-7.00012-5>
83. Das S, Dey R, Nayak AK. Artificial Intelligence in Pharmacy. *IJPER*. 2021;55:304-18. <https://doi.org/10.5530/ijper.55.2.68>
84. Expert I. Data Privacy and Security in Healthcare AI: Challenges and Solutions. *Health IT Answers* 2023. <https://www.healthitanswers.net/data-privacy-and-security-in-healthcare-ai-challenges-and-solutions/> (accessed July 21, 2023).
85. Top 6 Challenges of AI in Healthcare & Overcoming them in 2023 n.d. <https://research.aimultiple.com/challenges-of-ai-in-healthcare/> (accessed July 21, 2023).