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Review article

Artificial intelligence (AI) in hospital pharmacy: a comprehensive review

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ABSTRACT

This review examines the evolving role of artificial intelligence (AI) in clinical and hospital pharmacy services. A comprehensive literature search across PubMed, Scopus, Web of Science, Embase, and Google Scholar, covering studies up to July 2025, identified research using keywords such as artificial intelligence, machine learning, clinical pharmacy, hospital pharmacy, medication management, and decision support systems. Selected studies discussing AI applications, benefits, challenges, and outcomes were analysed through narrative synthesis.

Findings show that AI strengthens pharmacy operations by improving inventory accuracy, reducing medication errors, enhancing dispensing safety, and streamlining drug distribution. Machine learning and decision support tools support therapy selection, predict medication demand, detect drug–drug interactions, and promote personalised care. AI adoption also improves workflow efficiency, reduces administrative tasks, and enhances pharmacist training.

Originally developed for complex computational tasks, AI now transforms healthcare through digital record keeping, automation, and diagnostic tools. Its growing use in drug discovery, formulation development, and hospital pharmacy highlights its expanding impact on professional pharmacy practice.

Keywords: Artificial intelligence (AI), Machine learning, Clinical pharmacy, Hospital pharmacy, Medication management, Decision support systems, Inventory management, Medication errors, Drug–drug interactions, Personalised care, Pharmacy automation, Pharmacist training, Drug distribution, Digital health, Diagnostic technologies, Drug discovery, Formulation development.

INTRODUCTION

The integration of artificial intelligence (AI) and machine learning (ML) into pharmaceutical sciences has dramatically transformed areas such as drug discovery, clinical trial design, and personalised therapy. These technologies have introduced a new level of precision and efficiency, reshaping traditional research and development frameworks. With rapid growth in computational capabilities, improved algorithms, and expanding access to large datasets, AI has emerged as a foundational element in modern pharmaceutical innovation. This review explores the evolution of AI within the pharmaceutical field, its present-day applications, and its promising future. By bringing together insights from various disciplines, the article emphasises how AI-based advancements are addressing long-standing challenges in drug development and creating new models for delivering healthcare [1].

AI can be described as a scientific discipline focused on creating intelligent systems—primarily computer programs—that can perform tasks requiring human-like cognitive functions. These functions typically include data acquisition, construction of models for interpreting that data, drawing logical or probabilistic conclusions, and making iterative improvements through self-correction. In essence, AI relies on machine learning techniques to replicate human reasoning and problem-solving abilities. Through the integration of statistical methods and computational intelligence, AI technologies enable more accurate analyses and deeper interpretation of complex datasets [2].

In recent years, AI has become indispensable across numerous scientific and industrial sectors due to its ability to support high-level technical and research activities. Looking back over the past 25 years, the pharmacy profession has effectively adapted to growing prescription demands despite pharmacist shortages, rising operational expenses, and reduced reimbursement rates. The adoption of automation and supportive technologies has helped improve workflow efficiency while reinforcing accuracy, safety, and cost-effectiveness. Automated dispensing systems, in particular, allow pharmacists to dedicate more time to patient engagement and improve patient outcomes [3].

The use of computer systems in pharmacy can be traced to the 1980s, and since then, digital technologies have been incorporated into virtually every aspect of pharmaceutical practice—from recordkeeping and retail management to clinical research, drug storage, pharmacy education, and clinical pharmacy operations. With the advent of AI, the potential for further transformation is substantial. Several expert systems have been developed to support physicians in clinical diagnosis, and more recently, AI-driven programs have been designed to assist with drug therapy management. These include tools for monitoring drug interactions, evaluating therapeutic plans, and guiding formulary decisions. As AI continues to advance, its influence across various pharmacy domains is expected to expand, making it essential for pharmacists to recognize these emerging possibilities [4].

The objective of this article is to provide an in-depth review of AI-related topics, including its fundamental concepts, classification, and applications in hospital pharmacy, the pharmaceutical industry, and community pharmacy settings. Additionally, this work aims to promote awareness of AI as an integral part of future pharmacy practice and encourage pharmacists to develop the skills needed to participate actively in upcoming technological advancements [5].

Application of AI in hospital pharmacy

AI for automated medication dispensing systems

AI-powered automated dispensing cabinets help ensure accurate medication dispensing by tracking inventory levels, verifying prescriptions, and reducing human error. These systems also help pharmacists manage high workloads efficiently, especially in busy hospital environments.

Smart Inventory Management: AI enables automated dispensing systems to manage inventory in a predictive and efficient manner. AI can forecast future medication requirements accurately. This helps the system automatically reorder stock, avoid stockouts, reduce overstocking, and minimise wastage caused by expired drugs [6].

Robotic Dispensing Systems: In hospital inpatient pharmacies, these systems automate the preparation and distribution of unit-dose medications, ensuring rapid turnaround times and minimising the risks of human error in high-volume environments.

AI in personalised pharmacotherapy

AI plays a vital role in designing and managing personalised pharmacotherapy plans, especially for patients with complex or severe diseases who often require entirely new treatment approaches. These technologies make it possible to integrate and analyse large volumes of biological, chemical, and clinical data that are essential for guiding individualised therapy. In fields such as oncology. AI supports precision medicine by integrating tumour genomics, imaging findings, and past treatment responses to recommend the most effective chemotherapeutic agents or targeted therapies for individual patients. AI also contribute to the development of customised formulations and drug delivery systems, including 3D- printed medications designed specifically for the patient's physiological and therapeutic needs [7].

AI for predicting medication adherence

AI algorithms can identify patients who are at risk of poor medication adherence by analysing behavioural patterns, socioeconomic factors, and clinical history. By recognising these risks early, pharmacists can implement tailored interventions to improve compliance. Through this analysis, AI can determine which patients are more likely to experience adherence challenges, allowing healthcare providers to deliver preventive, individualised support rather than reacting after problems arise.

Furthermore, AI-driven platforms categorise patients based on their communication styles and personal preferences. This segmentation allows pharmacists to design targeted adherence-enhancing interventions such as customised reminders, patient-specific educational resources, or focused counselling sessions. AI supports improved medication adherence and overall treatment outcomes [8].

AI-assisted pharmacovigilance

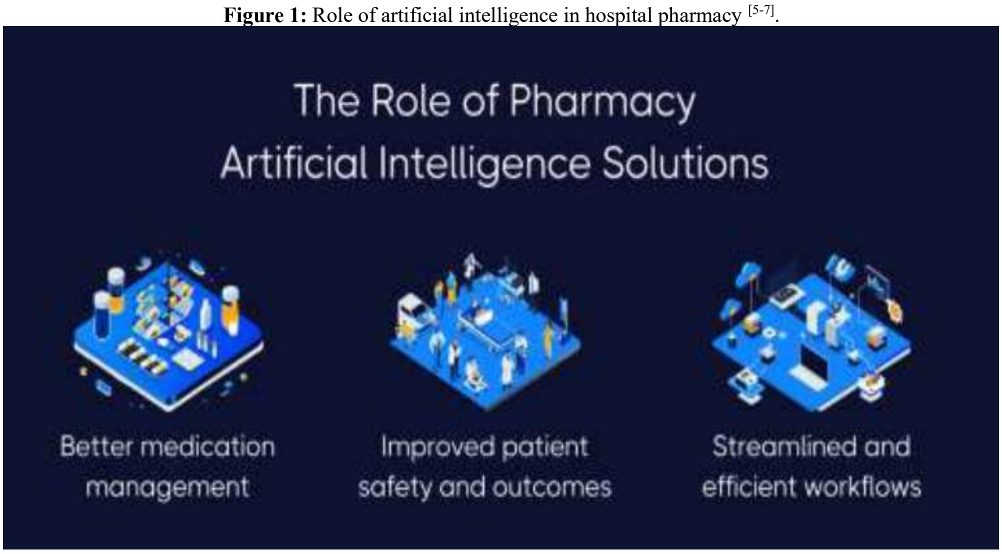
AI supports real-time monitoring of adverse drug reactions by scanning electronic health records, clinical notes, and patients' reports. Machine learning models detect hidden patterns that may indicate previously unknown safety concerns, enabling faster regulatory and clinical responses.

Clinical decision support systems (CDDS)

Clinical decision support systems, strengthened by artificial intelligence, are reshaping modern pharmacy practice by improving medication safety and supporting evidence-based decision making. The important application is medication appropriateness. AI algorithms assess various patient parameters, including age, kidney function, and associated diseases, to determine whether a prescribed drug is suitable for the individual. This assists pharmacists in preventing medication- related complication by identifying prescriptions that may pose safety concerns [9].

In addition, machine learning based predictive models enhance proactive patient care by identifying individuals who possess an elevated probability of experiencing an adverse drug reaction. By systematically examining extensive datasets derived from electronic health records, these models enable early detection of high-risk profiles, thereby supporting timely and clinically informed interventions by pharmacy professionals. Collectively, these technological advancements streamline clinical decision-making, curtail medication-related hazards, and strengthen the overall quality of pharmaceutical care [10].

Figure 1: Role of artificial intelligence in hospital pharmacy [5-7].



Artificial Intelligence (AI) is reshaping hospital pharmacy practice by enhancing medication safety, improving workflow efficiency, strengthening clinical decision-making, and enabling individualised patient care. By integrating machine learning, advanced algorithms, data analytics, and automation, AI supports both clinical and operational activities within the pharmacy [11].

Medication management and optimisation
Clinical decision support systems (CDSS)

AI-driven CDSS assists pharmacists by generating real-time alerts related to:

Drug–drug and drug–food interactions.

Known allergies and contraindications.

Required dosage modifications in patients with renal or hepatic dysfunction. These systems significantly reduce prescribing errors and promote safer medication use.

Medication reconciliation

AI tools review and compare medication histories from electronic health records (EHRs), helping to:

Identify inconsistencies

Avoid duplication or omissions

Ensure accurate medication lists during admission, transfer, and discharge

Inventory and supply chain management
Predictive analytics

AI forecasts

Future medication demand

Expiry risks

Stock replenishment needs

This prevents shortages, minimises wastage, and maintains adequate inventory levels.

Automated inventory systems

AI integrated with robotics enables:

Real-time stock tracking

Automated movement and organisation of supplies

Reduced reliance on manual counting and documentation

Robotics and automation in dispensing

AI-enabled robotic systems streamline dispensing tasks such as:

Counting tablets

Packaging

Labeling

Preparing unit doses

These technologies increase accuracy, reduce dispensing errors, and speed up workflow.

Examples include

Automated Storage and Retrieval Systems (ASRS)

Robotic systems for sterile IV compounding

AI in clinical pharmacy services
Drug therapy monitoring

AI continually analyses laboratory data, vital signs, and clinical indicators to:

Identify early signs of toxicity

Detect abnormal trends (e.g., kidney injury from vancomycin)

Support safer therapeutic decisions

Personalized medicine

Machine learning tools help predict:

Individual dose requirements

Expected response to therapy

Probability of experiencing adverse drug reactions

This promotes precision medicine and individualised treatment plans.

Pharmacovigilance and medication safety

AI systems examine large healthcare datasets to identify:

Adverse drug events

Medication error trends

Profiles of high-risk patient groups

This enhances medication safety surveillance and improves reporting accuracy

Workflow automation and efficiency

AI helps streamline pharmacy operations by:

Automating routine documentation

Managing task schedules

Providing rapid clinical insights

This frees pharmacists to focus more on direct patient-centred services [12].

Telepharmacy and virtual counselling

AI-powered chatbots and virtual assistant's support

Online medication counselling

Remote health monitoring

Patient education and query handling

This expands pharmacy services to rural and underserved populations.

Antimicrobial stewardship (AMS)

AI assists AMS programs by

Analyzing resistance patterns

Suggesting optimal antimicrobial choices

Preventing unnecessary antibiotic use

This supports efforts to combat antimicrobial resistance in hospitals.

AI in compounding and formulation

AI-guided robotic systems ensure

Precise preparation of sterile products

Reduced contamination and human error

Consistent quality in high-risk formulations like chemotherapy and TPN.

Most relevant types of artificial intelligence for hospital pharmacy

Machine learning

Machine learning refers to the development of computational systems that can independently learn, refine their behaviour, and adapt by detecting patterns within large datasets—without being explicitly programmed for every task. These systems evolve through experience, becoming increasingly adept at solving problems as more data is processed.

Supervised machine learning

In the hospital pharmacy, supervised machine learning can forecast treatment responses, including drug toxicity or therapeutic efficacy in individual patients. This capability supports personalised therapy selection and proactive prevention of adverse drug reactions. Hospital pharmacists can significantly influence these systems by defining meaningful clinical outcomes, identifying relevant patient characteristics to be included as predictors, and locating or generating datasets that contain the necessary labelled information.

Unsupervised learning technique

Unsupervised learning techniques function by uncovering inherent patterns, relationships, or groupings within unlabeled datasets. Instead of predicting predefined outcomes, these models autonomously classify data or detect underlying structures.

They are particularly valuable for revealing previously unrecognised trends, such as newly emerging adverse drug reactions or unidentified disease clusters.

A practical application within hospital pharmacy is the grouping of patients based on shared genetic, clinical, or biochemical characteristics to optimise individualised pharmacotherapy. By identifying natural clusters of patient profiles, clinicians can better tailor therapeutic choices for future cases [13].

Automatic learning

Automatic learning is a branch of artificial intelligence that empowers computer systems to enhance their performance in specific tasks by extracting insights directly from data, rather than depending on manually coded instructions. Through a wide range of algorithms, machine learning models examine large and complex datasets to identify hidden patterns, correlations, and structural relationships. These discovered patterns enable the system to make informed decisions, generate accurate predictions, categorise information into meaningful groups, and continuously improve as more data becomes available.

In addition, automatic learning supports adaptive behavior, meaning the system can refine its accuracy and efficiency over time without human intervention. This makes it an essential tool in fields such as healthcare, finance, engineering, and scientific research, where rapid analysis of vast datasets is required. By automating analytical processes, machine learning not only enhances decision-making but also contributes to developing intelligent systems capable of solving problems with increasing precision and autonomy [14].

Natural language processing (NLP)

Natural Language Processing is a specialised field within artificial intelligence that integrates computational methods with the complexities of human language. Its primary goal is to design models and algorithms that enable machines to comprehend, interpret, and generate spoken or written language in a meaningful and contextually appropriate manner [15].

A breakthrough within this discipline has been the emergence of large language models (LLMs). These systems, built upon principles of supervised machine learning and powered by sophisticated deep learning architectures, demonstrate an exceptional capacity to understand linguistic patterns and produce human-like text. By training on vast collections of annotated language data, LLMs autonomously learn grammar, semantic relationships, and discourse structures [16].

The advanced capabilities of LLMs—such as analysing intricate queries, generating coherent responses, and summarising extensive information—have opened new possibilities in healthcare and other fields. They support automation of administrative and clinical workflows, streamline the creation of medical documentation, and assist in the interpretation of scientific literature, and enhance communication and accessibility for patients and healthcare professionals [17].

In essence, NLP represents the domain of AI dedicated to examining, transforming, and making sense of human-generated text or speech [18].

Artificial neural networks (ANNS)

Artificial neural networks are computational models inspired by the architecture of the human brain. They consist of multiple layers of interconnected processing units, often referred to as artificial neurons. Each neuron receives input, performs a mathematical transformation, and passes the resulting output to the next layer. Through this mechanism, ANNs are able to learn relationships within data and progressively refine their internal representations [19].

ANNs are generally categorised based on their depth or structural complexity. Networks with only a small number of layers are called shallow models, whereas systems composed of many stacked layers are known as deep learning (DL) models. Deep learning architectures contain numerous transformation stages, allowing them to extract intricate, non-linear, and highly abstract features from raw data [20].

Deep learning

In deep learning networks, each layer applies increasingly complex operations as the information moves deeper into the model. The internal layers are responsible for generating abstract representations that are often unrecognizable compared to the original input. This hierarchical learning process requires large training datasets and substantial computational resources, far exceeding those needed for conventional machine learning approaches. the healthcare field, deep learning has demonstrated significant potential. It can support diagnostic decision-making by analysing medical images, laboratory results, and clinical notes with high accuracy. DL models are also employed to predict treatment responses, personalise drug regimens based on individual patient characteristics, and optimise therapeutic outcomes. Beyond clinical tasks, deep learning contributes to automating documentation, improving electronic health record systems, streamlining hospital operations, and identifying epidemiological trends across populations [21].

Benefits of artificial intelligence in hospital pharmacy

Artificial Intelligence (AI) offers a wide range of advantages that significantly improve the efficiency, accuracy, and quality of hospital pharmacy services. By integrating automation, data analytics, and machine learning, AI enhances both clinical and administrative functions within the pharmacy [22].

Improves medication safety

AI identifies potential drug–drug and drug–food interactions.

Provides alerts for allergies, contraindications, and dose adjustments.

Reduces the chances of medication errors and enhances patient safety.

Enhances accuracy in dispensing

Robotic dispensing systems minimise manual errors.

Automated counting, packaging, and labelling ensure precise medication distribution.

Improves reliability and reduces workload on pharmacists [23].

Optimises inventory and supply chain

AI predicts future drug usage patterns and stock requirements.

Prevents shortages, overstocking, and expiry-related waste.

Supports real-time inventory tracking and efficient supply chain management.

Supports clinical decision-making

AI systems analyse patient data, lab values, and treatment history.

Helps pharmacists make evidence-based therapeutic decisions.

Improves the quality of drug therapy and patient outcomes.

Strengthens pharmacovigilance

AI screens large datasets to detect adverse drug events and medication errors.

Assists in early identification of high-risk patients.

Enhances monitoring and reporting of drug-related safety issues.

Increases workflow efficiency

Automates routine tasks such as documentation and scheduling.

Saves time and allows pharmacists to focus on clinical responsibilities.

Improves overall productivity in the pharmacy department.

Enables personalised medicine

Machine learning predicts patient-specific drug responses.

Helps tailor doses and therapy plans for individual patients.

Enhances the effectiveness and safety of treatment.

Facilitates telepharmacy services

AI chatbots assist with patient counselling and answering medication-related questions.

Supports remote monitoring and digital pharmacy services.

Expands access to pharmacy care in rural and underserved areas.

Enhances antimicrobial stewardship

AI analyses microbial resistance patterns.

Recommends suitable antibiotics and dosing strategies.

Helps reduce unnecessary antibiotic use and combat antimicrobial resistance.

Improves quality and safety in compounding

AI-assisted robotic systems ensure accurate preparation of sterile products.

Reduces contamination, human error, and variability.

Ensures consistent quality in high-risk formulations like chemotherapy and TPN [24].

Recent advance in hospital pharmacy

AI aids in advancing public health monitoring. Advancements in machine learning algorithms and clinical decision support systems not only assist pharmacists in selecting optimal therapeutic regimens and detecting drug–drug interactions but also facilitate the delivery of personalised patient care and prediction of medication needs. In addition, AI integration was shown to improve workflow efficiency, reduce administrative workload, and enhance both pharmacist training and job satisfaction. Moreover, AI presents an opportunity for enhanced collaboration among various entities involved in the care of a single patient within the pharmacy setting. Through the use of advanced algorithms, AI can process large volumes of data such as historical sales figures, seasonal variations, local health trends, marketing campaigns, and external variables like weather conditions or disease outbreaks. By analysing this information, AI can accurately forecast the demand for different medications, enabling pharmacies to optimise their inventory levels. This proactive approach helps prevent stockouts of high-demand products and reduces the risk of overstocking items that may expire before they are sold. In addition, AI streamlines the reordering procedures in order to uphold the most efficient inventory levels. AI has the potential to enhance Automated Dispensing Systems. Potential drug interactions or patient allergies, thus greatly enhancing patient safety. In advance to the AI systems, it can analyse large-scale health data sets to detect trends in disease outbreaks, drug usage patterns, and other public health issues that may require a response by pharmacists or public health organisations [25].

Future scope of artificial intelligence in hospital pharmacy

AI-driven predictive analytics for medication demand and shortages, enhanced dispensing accuracy through automation and error prevention, and personalised patient engagement through chatbots and tailored reminders. AI will also free up pharmacists to focus on higher-level activities like medication therapy management, clinical collaboration, and public health. Operational efficiency: AI will automate routine tasks, such as prescription verification, inventory management, and dispensing, allowing for greater efficiency and accuracy. AI can assist in developing personalised medication regimens tailored to a patient's unique needs and medical history. It can enable more personalised patient counselling by providing pharmacists with detailed patient data and insights. The narrative surrounding technology and job loss often paints a grim picture [26].

However, when it comes to pharmacy, technology appears more as a driver of opportunity than of obsolescence. The future of pharmacy promises an expanded scope of practice, new career pathways, and a shift toward a more patient-centred approach - enabled by technology. As we move further into the 21st century, it is clear that the role of pharmacists will not become obsolete. Instead, it will continue to evolve and adapt, harnessing the power of technology to enhance our practice and deliver the best possible care to our patients. As pharmacists, we have an exciting future ahead - a future full of opportunities, not obsolescence [27].

CONCLUSION

The incorporation of Artificial Intelligence (AI) into hospital pharmacy practice is poised to fundamentally reshape the landscape of medication management. By elevating patient safety, streamlining operational workflows, and strengthening clinical decision-making, AI systems provide capabilities that far surpass those of conventional methods. Current applications—ranging from automated prescription verification and individualised pharmacotherapy to intelligent drug- discovery platforms and robotic dispensing—are already demonstrating significant improvements in accuracy, speed, and reliability. Despite these advancements, the transition to AI-enabled pharmacy systems is not without obstacles. Issues involving data confidentiality, cybersecurity vulnerabilities, financial investment requirements, and professional hesitancy remain major barriers. Furthermore, ethical questions related to algorithmic transparency, responsibility, and potential bias demand careful governance to ensure that AI is used safely, fairly, and equitably in patient care.

Looking toward the future, continuous technological progress is expected to yield even more sophisticated clinical support systems, including AI models capable of generating highly personalised therapeutic recommendations based on genomics and complex data analytics. With

With sustained research, infrastructure development, and organisational support, AI has the capacity to profoundly enhance hospital pharmacy operations—making them more efficient, patient-centred, and aligned with the growing demands of contemporary healthcare.

Beyond hospital settings, AI also carries transformative potential for community pharmacy practice. By automating administrative tasks, optimising inventory and demand forecasting, enhancing dispensing precision, and supporting data-driven decision-making, AI can significantly elevate productivity and workflow efficiency. Additionally, AI-based patient-engagement tools strengthen counselling, promote adherence, and contribute to improved clinical outcomes. Through predictive analytics and real-time monitoring, AI can also assist in preventive care planning, quality assurance, and identification of new business opportunities.

In essence, AI represents a pivotal force shaping the future of the pharmacy profession—promising increased operational efficiency, improved patient outcomes, and enhanced professional satisfaction for pharmacists, while simultaneously contributing to a more resilient and modern healthcare system.

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