Power System Technology
ISSN:1000-3673

Received: 06-01-2025 *Revised: 15-02-2025* *Accepted: 10-03-2025*

Artificial Intelligence in Pharmacy: Revolutionizing Drug Dispensing and Patient Safety

Saad Ali Abdulaziz Al Arfaj[1], Ismail Haider Baqtayyan[2] , Mohammed Khalid Abdullah Alrabiah[3] and Turki Abdullah Fahad alqahtani[4]

[1] Corresponding Author, Pharmacist, Arfajs@ngha.med.sa, Ministry of National Guard-Health Affairs, SA

[2] Pharmacist, baqtayyani@mngha.med.sa, Ministry of National Guard-Health Affairs, SA

[3] Pharmacist, Rabeeahm@ngha.med.sa, Ministry of National Guard-Health Affairs, SA

[4] Pharmacist, Qahtanitu@gmail.com, Ministry of National Guard-Health Affairs, SA

Abstract

In this article, the role of robotics in pharmacy, which uses artificial intelligence to assist in the dispensing of medications, will be reviewed. The advancements of pharmacy robots in regard to vial medication dispensing and blister medication dispensing will be discussed. An overview of currently available pharmacy robots will be provided, and insight into the future of pharmacy robots will be shared.

821,000 people die annually worldwide due to medication errors. About 22.5% of these deaths can be prevented by barcoding patients near the point of care or by the double-checking principle. American hospitals spend approximately $0.56 million annually for additional verification time, impulse buying, inaccurate design, seniority, and high cost for familiarization. 91% of patients with tamper-resistant prescription pads experienced one or more tampering incidents. Thus, the need to remediate a complexity issue in pharmacy robotics is of paramount importance. This remediation can be accomplished by a new generation of pharmacy robotics that utilizes multi-core computing systems for parallel processing of both probabilistic and deterministic tasks of pharmacy robotics systems.

115,374 medication errors occur nationally each day, resulting in 1,042 patients with serious injury. Personal digital assistants collect excessive data relevant to a patient's medications and health issues. Personal digital assistants have not lived up to expectations, and various systems have experienced technical problems. The need for a single integrated IT system and communication mechanism remains unmet despite the recent convergence of several disparate technologies. Patients prefer a single point of product initialization; however, unaddressed are physical formats which should be compatible, performant, compact, and robust for different environments. For home use, it is important that systems be autonomous

Power System Technology
ISSN:1000-3673
Received: 06-01-2025 Revised: 15-02-2025 Accepted: 10-03-2025

and unaware of the user's current or past experience. Solutions to these complexity issues that plague pharmacy robotics systems less depend on newly developed multiple standards as heavy machinery does but more on a new science of robotics.

Keywords (8 words only)

artificial intelligence; pharmacy automation; drug dispensing; medication safety; pharmacy robots; AI in pharmacy; pharmacist's practice

1. Introduction to Artificial Intelligence in Pharmacy

The use of artificial intelligence has recently gained significant attention in many fields and industries, with a focus on its applications to enhance productivity, efficiency, and many other benefits. AI in simple terms can be explained as the ability of a system most often computers to act intelligently and therefore perform tasks that otherwise require human intervention. The exciting aspect of AI is its increasing applications and studies within the pharmaceutical field, which have attracted the attention of scholars and researchers. The purpose of this article is to review pharmacy robot technology as one of the most important and available technologies of artificial intelligence in pharmacy (R Alahmari et al., 2022).

Pharmacy robots are software-enabled machines that can manipulate their physical environment, usually with mechanical components, to carry out such tasks as drug monitoring, packing, dispensing, or other tasks in a pharmacy environment and observe, collect, or analyze data to carry out other tasks. Robotics in pharmacy is considered a significant recent development in pharmacy practice that has the potential to enhance pharmacy-operation quality, productivity, job satisfaction, and continue to attract the interest of pharmacy commission resources. Factually, pharmacy robots will not replace a pharmacist in the fields of expert judgment, patient counseling, or physician recognition and communication (Ioana Visan & Negut, 2024).

Historically, the use of a robot to dispense medicines or diagnose diseases means a huge change in practice, but the pharmacy robots started to appear in retail pharmacies worldwide in the 80s. The technology consists of an accumulator, providers related to dermatology, cameras, total stock, dispensing unit mechanism, and several other subsystems and facilities that have developed since then. Hence, dispensing robots can be divided by location into community, hospital, and both robots. Packaged robot technologies depend on providers that specialize in that activity, with a tendency of community robots to offer automated product-placement options. As with any new business, protecting that business and its liability from loss is vital. One of the risks that a pharmacy often encounters is the dispensing of the wrong medication, either due to mislabeling or packaging.

Received: 06-01-2025 *Revised: 15-02-2025* *Accepted: 10-03-2025*

2. Historical Overview of Pharmacy Practices

Six hundred years ago, the license for necessary drugs and treatment without a doctor came to a pharmacist. But if we look at the topographies of other countries, this branch was established long before us. Aristotle gives core medicinal ideas; Aesculapius, the Curears, and other Greeks used plant drug therapy. Even later, it worked as a licensed job. The opium war, on the other hand, opened the eyes of many southeastern Asian countries, including us. Drugs, which we had never invented or implemented before, were now seen in pharmacies. The 78-year reign of Emperor Shah Jahan not only drew the Master of Taj Mahal's great design but world-famous drugs as well, and the first pharmacy in English came into existence. For many years, this evolved the art and science of calling medicines by specific names according to method, preparation, use, and case of their application. Even being titled "Doctor of Pharmacy" (PharmD) was once "Doctor of Materia Medica" (D.M.M.). Like medical terminology, its pharmacology is widely borrowed with alterations from Greek and Latin. As a result, ART rather turned into SCIENCE with the increasing wheel of time, and drugs increased from hundred to thousand. But man, even learned, never has the capability to remember so many things exactly and all at once. The confused drugs and the victim patient were then at hand. And this was the alarm signal for a search out of something mechanically to do these tasks by AI (R Alahmari et al., 2022).

The 19th Drug Convention paved the way for the proposal of more plans and establishment in this regard. In 1953, there were only two computer-based but unsuccessful models that could store static information of formulary and atlas. But in 1959, Dr. Noyes invented the first electronic robot, accepting a reliable boom in the pharmacy sector. In 1960, reaffirmation of thirst across the globe led to the invention of more robotic models and full automation away from personal approach concentration. Lockhart understood the need for computerized medical records, instructions across heartbeats, and generating proper out-of-turn medicine in a clinical trial. Penicillin until today was the cause of most accidental death, and drugs invented for salving this gradually endangered life tremendously at hand of mingling and high-density flow rates. As it was still exponential, personal calculation was given hopeless; therefore, a search out was at hand for computer programming contactable by at least marginal approach. This similarly and step by step operated the whole pharmacy sector from the gall to cabinet of formulation, machine room, and dispatch.

3. Current State of Drug Dispensing

Since the development of pharmacy robots, intelligent robots have grown to completely take care of dispensing approximately 79% of medications in hospitals. Robot dispensing has a stronger market and is becoming the mainstream because it improves working efficiency. The applications of dispensing robots are varied, such as robotic storage systems and semi-manual dispensing robots, and there are two dispensing robots successful in the market today. Robot

Power System Technology
ISSN:1000-3673
Received: 06-01-2025 Revised: 15-02-2025 Accepted: 10-03-2025

dispensing systems can dispense for various environments, such as large volume parenteral (LVP) dispensing or units dispensing (R Alahmari et al., 2022). Furthermore, robots used in pharmacy have been adopted internationally throughout the world. Cities of various sizes have been able to take advantage of dispensing robots to facilitate pharmacy work and improve dispensing efficiency. In Saudi Arabia, robot dispensing technology has been applied to many city hospitals, which serve as models for Saudi Arabia on the international stage. Robot dispensing technology reduces working hours and labor costs and increases dispensing efficiency and accuracy; it is a wise investment for hospitals. To minimize the drawbacks of the conventional pharmacy dispensing system, several improvement measures could be considered. Computerization and mechanization are reengineering methods that could be applicable for gradually improving the dispensing process from conventional manual methods to computer and robot-monitored fully automated dispensing. The computer and robot-monitored medication dispensing system effectively overcomes drawbacks of the conventional pharmacy dispensing system. Providing marginal facilities, e.g., economical PCs, barcode readers, dispensing carts, weighing scales, or dispensing robots, generally requires less finance than more advanced and sophisticated systems. These systems have been successfully implemented in many hospitals globally; thus, sufficient experiences and models are obtainable to understand the major issues confronting many hospitals in a country like Saudi Arabia.

4. The Role of AI in Drug Dispensing

The health informatics system can take the form of an integrated pharmacy management system at the hospital level. Integrating a pharmacy management system directly with the hospital's health informatics system ensures real-time connectivity of the hospital and pharmacy systems and on-time data exchange. This integration allows pharmacy personnel to view a patient's medication profile history stored in the hospital health informatics system. Accordingly, they can instantly identify violators of drug dispensing regulations and prevent drug dispensing errors. Such integrated systems have been used in hospitals or healthcare institutions in various developed countries. However, this technology is rare in developing countries like Saudi Arabia. Pharmacy management software and communication technology between hospital health informatics systems and pharmacy management systems must be established in the developing world (R Alahmari et al., 2022). Commonly identified prognostic schemes like molecular markers and clinical stages will need interpretation and will be impossible to use without artificial intelligence-based algorithmic classification.

A complete predictive and prognostic metamodel must ultimately take form; however, it is probable that subsets of features and a few model parameters will be developed with reasonable performance (Ioana Visan & Negut, 2024). The estimation of skill construction is required for a good use of probabilistic metamodels. Moreover, a comprehensive measure of

Power System Technology
ISSN:1000-3673
Received: 06-01-2025 *Revised: 15-02-2025* *Accepted: 10-03-2025*

the processes generating the observable chemical features is required. The first sources of chemical descriptors in a predicted databank may be based on empirical structures. However, for some class of hearth models, new generation rates are extremely slow and thus, bottlenecks must exist on the estimation of excess free energies. The position of such bottlenecks is not known so far. If these bottlenecks are on viscous fluids of high fall time then existing slower chemistries will perhaps have strong kinetic constraints. Robust integration of amino-acid design and the physical modelling of folding will need to be explored. A similar strategy could also help remedy the lack of novel energetically codpictures of mutant conformations and cavities for which the current databases are essentially empty. In all cases, the methods deployed should be maximally simple making use of already existing forcefields and statistical models and synthetic routes.

5. AI Technologies in Pharmacy

Two of the most important applications of AI in pharmacy are robot technology and medication dispensing technology. In the current time, robot technology is a revolutionary and popular tool in various enterprises. It is important to know that AI has gradually developed into various forms of intelligence for its broad definition. The current development of AI can be divided into areas and degrees (R Alahmari et al., 2022). The AI research field comprises mature technologies such as machine learning (ML) for the observation of situations and predictive analysis, extraction of knowledge, augmentation of computing problems, and natural language processing (NLP) to comprehend human language or behavior. There are frontier technologies including knowledge-based systems, swarm intelligence, robotics, and true intelligent agents that entail products that are uncommon or have not been commercialized yet. AI applications around the globe are rapidly evolving, although some have yet to be released in pharmacy and drug development fields. The feasibility of the application depends on the performance of the pharmaceutical industry in combination with the present AI development stage.

Drug dispensing technology is an advantageous application for AI in pharmacy the increasing number of prescribed drugs poses challenges for patients and healthcare providers in drug dispensing and administration. It has been known that only a small proportion of prescribed drugs are likely to be used by the patients, but it is uncommon to switch from one prescribed drug to another at the same time due to the limitation in collecting all available data or processing them. In the industrial sector, pharmacy robots are deployed to dispense medication and alleviate the above-stated problems. A pharmacy robot is a pharmaceutical device with conditions for the computerization of drug dispensing and packaging. Drug dispensing costs approximate to 20% of all pharmacy resources and expenses.

Received: 06-01-2025 Revised: 15-02-2025 Accepted: 10-03-2025

5.1. Machine Learning Applications

Machine learning presents several applications that help view modern automation and its importance in pharmacy. Complex data sets can be translated and comprehended using ML (Singh et al., 2023). In addition, ML algorithms are used in classification, clustering, regression, search, recommendation, and filtering tasks. Computational power is of greater importance in IC as a specialized algorithm would be of no use. ML tools would help transform and make sense of large and complex datasets into simpler pieces. Supervised-learning algorithm fits into predictive modeling, where patterns are discovered from data sets using trained labeled examples. Association analysis shows relationships between variables using the unsupervised learning algorithm. For example, a user who views Psi could also view Gamma using recommendations. C4.5 is a mapping tool available in the WEKA ml toolkit, which builds a decision tree by inducting past information on monthly payments. In contrast, K-means clustering technique is used as a flat algorithm when data sets are too large for other techniques. This assigns clusters based on the smallest distance threshold. This histogram clustering algorithm can analyze data sets using numerous histograms generated according to dimensions. ML applied computing is widespread in medicine, pharmacy, and health-care sectors. Automated prescription and dispensing systems improve dispensing accuracy and improve pharmacy productivity. With patient safety and personal safety, pharmacy is a necessary part of health care. Data inclusiveness is variable; prescription and dispensing phases and electronic dispensing record types handle full or partial data sets. The work presented a systematic way to examine the pharmacology dispensing process to enhance patient safety. Automated prescription checking was undertaken using a rules-based model, with a learning-based model improving upon this. Prior continuous learning was implemented to make recommendations from collated data and predict possible lost items. This approach might be extended to personal safety, considering robots for speed and process safety in dangerous environments outside the institution.

5.2. Natural Language Processing

Natural Language Processing (NLP) is a subfield of artificial intelligence (AI) that focuses on the interaction between computers and human languages. It involves the development of algorithms and models for the automatic processing of text and speech, with the goal of extracting actionable information. The explosion of accessible data on the web, the rapid growth of digital behavior, and the increasing number of documents, articles, books, forums, tweets, and blog posts in social media have created a huge potential for NLP applications to improve productivity, collaboration, and performance in every endeavor, including the pharmaceutical domain. While COVID-19 was present, NLP aided in data extraction, with the textual data extracted being used in conjunction with a knowledge graph for computational epidemiological modeling (Singh et al., 2023) and clinical trial data being

Power System Technology
ISSN:1000-3673
Received: 06-01-2025 Revised: 15-02-2025 Accepted: 10-03-2025

modeled for the predictive determination of trial-related data. During the health crisis, Pharma companies and agencies began releasing information to inform the public about the ongoing situation. Almost in real time and around the globe, such textual data were broadcasted in social media. As a consequence, it became of utmost importance and urgency to monitor the machinery behind the human reaction to the crisis and the spread of misinformation in order to tackle users' attitudes and perceptions concerning COVID-19. And NLP is the field of science that, together with social media mining techniques, can be leveraged to analyze such large amounts of textual data.

Natural Language Processing is used in drug safety monitoring. As drug information originates from written reports in natural language the initial step for its automatic processing is the automatic recognition of drug name mentions. This task is nowadays known as Drug Named Entity Recognition (D-NER). Such mentions are often ambiguous and multiword expressions requiring the identification of the exact mention, the target drug entity, and its drug normal form to refer uniquely to the drug entity. An annotation scheme for the construction of a D-NER annotated corpus is proposed covering different mention types, their roles in the narrative, and their identification in the text. D-NER systems based on several machine learning algorithms are trained on publicly available resources and the custom corpus. The D-NER systems allow the identification of mention instances of different mention types and their mapping to the target drug entities. The best performing D-NER system was utilized in a pipeline for the extraction of drug-event pairs from drug safety monitoring reports.

5.3. Robotic Dispensing Systems

Diminishing workforces in health systems are a global phenomenon that dramatically reduce the availability of pharmacy professionals in understaffed areas. In view of global and local health, epidemic, and safety crises, this reality has raised demands for a higher degree of resilience followed by more automized and efficient processes in the pharmacy departments of hospitals. While issues of vacant jobs in pharmacy departments could take years to improve, pharmacy automation systems are increasingly implemented. Despite long standing critiques of the massive expenses of pharmacy robots, other alternatives will not lead to the much desired quality drift and more health security. As the quality drift will not involve a substitution of professionals, the automation of pharmacy processes will not differ from the introduction of e-prescription or online pharmacy services or vaccination automations, but represent the digitalization of the already available service technology (R Alahmari et al., 2022).

Many dispensing robots are designed to store, sort, and dispense drugs in pharmacies and are usually installed in connection with the pharmacy's other systems, for example the dispensing or patient safety system in the hospital information system, the inventory

Power System Technology
ISSN:1000-3673
Received: 06-01-2025 Revised: 15-02-2025 Accepted: 10-03-2025

management system, or fulfillment systems. The basic components of dispensing robots are often comprised of the input and dispensing side, the transport belt, and the onsite or remote service station. Control cabinets are usually integrated in the notice housing. The input side is designed to support pharmacists when inputting drugs into the machine. They can be picked up manually from tote trays using an external barcode scanner or inserter. After input, the drugs are automatically stored in special baskets. When stored, barcodes are compared and inputted drugs are matched with the information stored in the pharmacy's system. Inexcusably disposed drugs are manually sorted out again. The transfer of the baskets can also take place before any output, the documentation and dispensing steps are performed on the dispensing side.

6. Enhancing Patient Safety with AI

Pharmacists have long been considered the key players in the safe handling, dispensing, counseling, and providing of medications. Although the workflow in community pharmacies differs from one pharmacy to another, there are general activities involved in this workflow. These activities include the reception of prescriptions, processing of prescriptions, dispensing medications, counseling patients, and finally re-stocking of the received medications. Each step must be performed correctly to avoid errors and mistakes that could compromise patient safety (R Alahmari et al., 2022). Medication dispensing and attention toward the health of each patient are key roles of a pharmacist which could be enhanced through the application and use of pharmacy robots. The objective of this article is to conduct a literature review of well-known FDA-approved pharmacy robots and pharmacy medication dispensing technology. Robots in pharmacies could take away the responsibility of hard work from human pharmacists by undertaking medication dispensing and dispensing tasks. By applying the pharmacy robots into existing pharmacies preventive and corrective initiatives, one can expect to enhance the available time of each pharmacist to serve a wider base of patients in a higher quality manner. The contribution of this article to pharmacy practice is to touch upon the FDA-approved cutting-edge pharmacy robots. The article also highlights the possible impacts of their adoption on the future practice of pharmacy. Upon establishing the roles of pharmacy robots carefully this could lead to achieving a win-win situation for both pharmacists and patients.

7. AI in Medication Error Prevention

Robotic systems are widely used in theatres, warehouses, hotels, restaurants, supermarkets and parks. AI technology is now integrated into the robotic systems so that they can execute a wide variety of intelligent behaviours (R Alahmari et al., 2022). Consequently, in pharmacy, AI is briskly recognized as the most substantial technology affecting medicine dispensing. It is generally accepted that robotic dispensing systems lead to more precise and faster drug dispensing than the traditional manual system. Nevertheless, expectable direct mechanical

Power System Technology
ISSN:1000-3673
Received: 06-01-2025 Revised: 15-02-2025 Accepted: 10-03-2025

failure such as paper jam, gear blocking, and belt distortion is not the only source of malfunction. In this work, some unexpected errors are examined that did not arise from direct mechanical failure. Other functional failures took place due to erroneous input data from human operators or manufacturer faulty products, respectively. Anxiety related to the convenience of the robotic dispensing system in pharmacy is discussed. At last, suggestions for risk minimisation are proposed.

The actively integrated networks of technological systems should remain continuously aware of their local environment and the state of the overall system so that they can prevent errors and assure the safety of the processes. A precondition for safe system operations is the ability to detect a malfunction and its early warning so that timely action can be planned and executed. In most of the reported systems, there are no 'watchdogs', and limited attention is paid to the monitoring of the risks that lead either to the malfunction of the machinery as such, or to subsequently increased risk of severe consequences, as could take place due to the human factor in the case of a robotic dispensing system. AI is now incorporated into a robotic dispensing system to enhance management decisions and machine intelligence levels. Failure analysis of the robotic dispensing system, expecting scenarios of erroneous behaviour and risk, and suggestions for failure prediction will be proposed to lessen medication dispensing risk.

8. AI-Driven Personalized Medicine

Artificial intelligence (AI) is paving the way for personalized medicine, promising to revolutionize healthcare from prevention through early diagnosis and intervention to precision treatment. The impact of AI and machine learning on precision medicine is enormous, with the potential to make accurate predictions of therapeutic responses and transform healthcare. AI provides robust predictive models to extract insight from vast datasets. Unsupervised learning, supervised learning, and reinforcement learning are widely utilized paradigms to analyze biological data (Singh et al., 2023).

Patients diagnosed with a disease can be categorised into subtypes based on a large variety of homogeneous molecular features using unsupervised learning algorithms, such as hierarchical clustering, k-means clustering, t-stochastic neighbour embedding (t-SNE), and Principal component analysis (PCA). With these subtypes, drugs can be prescribed to particular subtypes. The response of subtypes to different therapeutic options can be predicted using supervised learning algorithms, such as decision trees, random forests, support vector machines (SVM), and K-nearest neighbour classifiers.

After a successful treatment, it is important to monitor responses of a disease for relapse, which requires predictive models capable of continuous online forecasting. Reinforcement learning algorithms, such as Markov decision processes, Bayesian networks, and deep

Power System Technology
ISSN:1000-3673
Received: 06-01-2025 Revised: 15-02-2025 Accepted: 10-03-2025

learning networks, allow decision making based on the analysis of time-evolving data streams. These predictive models, once successfully trained, are digital companions of physicians, working together with physicians to improve therapeutic outcome, efficacy, and safety. Automated generation of treatment decisions from pharmaceutical companies are models that can adjudicate whether certain treatments should be applied or not.

9. Data Management and AI Integration

The emergence of artificial intelligence (AI) and machine learning (ML) and their applications have profoundly transformed technology. AI and ML models have evolved with immense competition between technology firms to build capable computational hardware, capable algorithms, and vast amounts of data using supercomputers for data optimization. These innovations have crossed over to pharmaceutical domain research, where, like other domains, ML's effectiveness in prediction has led to a boom of programs utilizing data to drive hypothesis formulation and testing increments in biological and chemical spaces.

At present, the academic literature comprises general appropriateness overviews of ML methods for molecular representation and target selection approaches. The number of ML models and ML methods incorporating only features belonging to the pharmaceutical and biological domains instead of general AI-related ML predictive models has greatly increased.

AI revolutionizes current drug development practice at three main points in the research and manufacturing pipeline of the pharmaceutical industry. At the outset, AI is poised to considerably increase the efficacy of the pharmaceutical industry. There is a revolution at the level of the most meaningful chemical entities, with systems being developed to highlight chemical space understanding and, in conjunction with success probability estimations, chemical generation. At the scale of the hundreds of drug recycling, automatic drug discovery systems are being developed, capable of producing drug candidates from scratch.

Safety is a vital component of the health care continuum. Risk to the patient can derive from treatment error and failure, but it can also derive from the dispensing of the wrong drug, wrong dose, or wrong formulation. The pharmacist is key in ensuring that risk to the patient is reduced across the entire continuum.

With technology advancing rapidly in pharmacy, reliance on robotics and AI is becoming ever more evident, especially in ensuring accurate and efficient dispensing. The errors of human operators are often a consequence of the rapid growth of the number of available drugs and the additional complexity across which they are prescribed, processed, and dispensed (Singh et al., 2023).

Power System Technology
ISSN:1000-3673
Received: 06-01-2025 *Revised: 15-02-2025* *Accepted: 10-03-2025*

10. Ethical Considerations in AI Use

While the use of AI in pharmacy has clear benefits, it also presents concerns. Questions like how AI will replace human tasks or consequences for errors must be addressed. Caution is warranted in its current nascent state, as issues of bias, fairness, and data security, among others, are still being worked out. AI has been challenged with several ethical issues that malign its value and raise concern over its use. Evidence suggests that these issues can be addressed by having inbuilt system checks, robust methodology, and, overall, transparency (Singh et al., 2023).

Bias in data can affect everything that comes from it. An AI model trained on data that itself contains bias, whether intentional or not, is more likely to yield a model that also exhibits bias. This can affect predictive modeling, affecting provision of medications differently based on race, age, etc. Biased outcomes denigrate the health monitoring efforts, providing inadequate treatment to those who need it. Intense effort should be engaged in curating and preprocess training data to ensure adequate diversity within it. Monitors and audits should be applied to identify and correct demographic or societal biases that persist in AI systems post-deployment. Employers can insist upon fairness bonds, having AI firms provide assurance against biased outcomes. Fairness-aware algorithms and assuring fairness constraints can guarantee spatially equitable treatment.

Data privacy is the primary issue, as personal information is being shared. AI models need to be designed with privacy principles. Strong submission and extraction controls have to be put in place, along with regulations, in order to adhere to guidance, with monitoring and occasional reviews of data access. This will ease fears about how patient data handled by AI models. In most cases, data, however anonymized, are still exploitable. Anonymization ought to be regarded as a last resort, with release to a trusted enclave in place of deidentification methods providing a clearer choice.

10.1. Patient Privacy Concerns

The rapid advancement of the internet and AI has transformed the entire world, including the healthcare sector. However, these advancements also present an array of ethical issues such as bias and prejudice, data protection and privacy, the possibility of job loss, and misuse (Singh et al., 2023). These ethical issues impede the transition of AI into healthcare, which is why many stakeholders have asked for regulation. Professional associations and organizations have voiced concerns about the impact of AI on human rights, the healthcare workforce, public trust, scientifically sound health policy, and free and open inquiry in the areas of health and research (R Alahmari et al., 2022). As a result, governments and international organizations have released strategies, frameworks, and principles to ameliorate ethical issues, as well as challenges for applying or upholding them. A regulatory strategy

Power System Technology
ISSN:1000-3673
Received: 06-01-2025 Revised: 15-02-2025 Accepted: 10-03-2025

should contain obligatory standards and penalization for outliers. Comprehensive regulations may be hard for emerging technology, as these would impede innovation while risking international competition and economic growth. AI algorithms should be auditable and explainable. Disclosure acts as a guide for the professionals, policy-makers, and users; conversely, nondisclosure may impose responsibility on developers.

AI is increasingly being utilized in the field of pharmacy, especially with the automation of the dispensing process, through the introduction of dispensing robots. Introducing robotics into pharmacy departments is a significant step towards the future as it improves dispensing efficiency and enables the re-engineering of pharmaceutical services, which leads to maximum utilization of space in hospital pharmacy departments. In addition, serving as an electronic buffer allows robots to avoid line-queue problems and gaps in service accountability. The usage of dispensing robots also improves the written and electronic communication terms between the central pharmacy and wards while enhancing the quality of patient care through the dispensing of sufficient medications shortly after they are prescribed and reducing wastage from medical returns. Centralized pharmacy departments can fix shortages of drugs in the ward pharmacy by distributing them more quickly, as dispensing robots can dispatch medications on an "as-needed" basis, especially medications that are in high demand. The dispensing robot thus improves therapeutic efficacy through compliance with the prescribed medications and prevents adverse interactions through the integration of drug dispensing and drug interaction monitoring. As a new advancement of the traditional pharmaceutical dispensing system, the use of AI is widely expanding in the pharmacy department of healthcare institutions.

10.2. Bias in AI Algorithms

AI algorithms increasingly influence human lives in critical areas, such as healthcare, insurance, and criminal justice. Unfortunately, these applications rely on existing biased data or flawed modeling processes, at times producing racially or socially discriminative results. AI algorithms have been shown to discriminate against certain ethnic and gender groupings in healthcare applications. For example, an AI model accurately diagnosed skin cancer using images of skin lesions. However, it was discovered that the algorithm had been trained on images of patients with fair skin and was unable to detect skin cancer on patients of color. Similarly, a widely used AI algorithm to identify suitable candidates for care management programs in the health insurance market was found to underrepresent African American patients and exacerbate inequalities. Most data-driven algorithms utilize available historical datasets containing socio demographic data, such as ethnicity and age. Bias present in historical datasets can inadvertently be learned and propagated in future predictions, unintentionally leading to socio demographic discrimination.

Power System Technology
ISSN:1000-3673
Received: 06-01-2025 Revised: 15-02-2025 Accepted: 10-03-2025

Pre-processing is the most frequently adopted bias mitigation technique. Majorities of algorithms require extensive datasets for training, including labeled data. Unfortunately, labeled data is typically limited in the case of medical experimentation. Ensuring that the collected datasets cover diverse groups is critical. Trials should include datasets from a range of ethnicities and medical histories, thus ensuring that training data comprises diversity. A balanced training dataset ensures a more flexible learning process, producing a generalizable AI model and assisting in minimizations of bias considerably. Along with biased datasets, unintended biases can also arise from restricting or wrongly selecting features during the data collection process. In the AI-based healthcare regulatory system, skin color and socio economic groupings unnecessarily provided a bias for selecting datasets and could accordingly lead to fairer groupings being excluded from the model building process.

AI systems operate in complicated environments, where decisions might reinforce biases not identified during training. Monitoring AI systems after delivery optimally identifies and corrects biases missed in the modeling process. Monitoring measures can stop false positive drug-drug interactions in real-time pharmacovigilance systems or avoid drug resistance in personalized pharmacological treatment. After something wrong claims were classified as low risk, the government had to revise the law directing the collection of input features used to make predictions. Such monitoring requires additional knowledge, which is often complex, documented, and costly for stakeholders. Hence, analyzing the tradeoffs between monitoring feasibility and knowledge availability is paramount. That can be initially achieved by assessing intended uses and possible failure conditions. Balancing social values, such as fairness and accuracy, is closely related to monitoring.

11. Regulatory Framework for AI in Pharmacy

As sectors continue to digitize, this brings great potential opportunities as well as unprecedented risks and safety concerns. The pharmacy industry is undergoing radical disruption in the form of Artificial Intelligence (AI). By leveraging AI technologies, pharmacy can better dispense the right drug to the right patient at the right time. Importantly, drug dispensing and medication administration are safety-critical tasks. With patient safety as the central focus, there is great potential but also unavoidable responsibility in adopting AI in pharmacy. Regulatory frameworks will need to evolve to provide timely guidelines to industry stakeholders, while not stifling the innovation potential. The regulatory approach to applying AI in pharmacy is similar to the broader medical device regulatory approach. It typically has three dimensions: ensuring the quality of AI development (pre-market), fostering reliability in real-world deployment (post-market) and enabling transparency for accountability (all stages). There are different regulations and guidance documents issued by various authorities governing these dimensions. This review article can help pharmacy

Power System Technology
ISSN:1000-3673
Received: 06-01-2025 Revised: 15-02-2025 Accepted: 10-03-2025

stakeholders navigate through the following tenets of the pharmacy regulatory framework for AI (Han & Tao, 2024)

Drug dispensing is one of the most safety-critical tasks in pharmacy. Automated dispensing systems and robotic medication dispensing systems are not new in pharmacy. There are already widely adopted commercial products that can store a large number of drug varieties in a compact footprint, reducing the risk of drug dispensing errors. However, the safety and efficacy of these systems in complex pharmacy workflows are hard to guarantee. Patients sometimes receive wrong drugs or wrong routes of administration, calling into question the effectiveness of these dispensing systems. There is immense opportunity in monitoring automated drug dispensing workflows with AI technologies. Video data can be algorithmically processed to ensure that drug dispensing adheres to the multi-step, multi-image multi-frame procedures prescribed by pharmacists. The supervision leads to minimizing the risk of human factor problems such as lapse of attention and misinterpretation. If a safety issue arises, a detailed investigation with the help of AI-generated event timelines can be made to improve the workflow (Singh et al., 2023).

Medication administration is another safety-critical task in pharmacy. It is traditionally done manually by staff nurses. Unfortunately, the medication administration workflow can present multiple points of failure that can result in medication administration errors. There is immense opportunity in monitoring medication administration workflows with AI technologies. Video or video frame data can be algorithmically processed to ensure that medication administration adheres to the rules prescribed by it the workflow. The supervision leads to generating a record of whether rules are followed and generates timelines of adherence/nonadherence events to assist in subsequent QA investigations. It is imperative that human-readable overviews of the supervisions and decisions of the algorithm are generated.

12. Case Studies of AI Implementation

Implementation of AI has begun recently across the world. Therefore, literature on the issues relating to its implementation is still limited. In the following paragraph, a few case studies are presented to highlight the use of AI, the machines used, and the countries in which they are used (R Alahmari et al., 2022).

In 2021, the AI-based digital pill-popping robotics system known as PillPopper was invented and adopted in Korea. The automatic picking robot for dispensed pill was made with a 360-degree rotation robot arm and a vision system to measure and analyze the image in a digital pill popper unit. The deploying results showed that a total of 358,299 packaged pills in a 3-week evaluation period could be dispensed with perfect precision by the proposed system. The pill popper could pick filling boxes over 3 months without a hitch. It is expected that the

Power System Technology
ISSN:1000-3673
Received: 06-01-2025 Revised: 15-02-2025 Accepted: 10-03-2025

introduction of this technology will solve a labor shortage in Korea and eliminate risks of 10.7% manual dispensing errors.

In December 2016, Orion, a computerized automation pharmacy-based medication dispensing robot, was introduced at the SNUH Division of Clinical Pharmacology, Daejeon, Korea. Orion was capable of completing all tasks from the initial dispensing of patient-specific medications to the final transfer for administration within the same unit. This system allowed pharmacists to focus on medication management, minimizing the frequency of work-related musculoskeletal symptoms without threatening medication-safety of a medical institution.

Several initiatives had been launched in the past to study and develop robots in the pharmacy field. These projects were generally limited in scale, which managed to conduct basic research. Therefore, no off-the-shelf products had been introduced out in the markets. In no event, do they consider a full automated pharmacy system that encompasses the overall procedure from medication management to drug dispensing. The researchers proposed a semi-tolerant robot-integrated pharmacy system to raise and overview the detailed implementation and integration schemes. The system accommodates multi-robot and multi-patient management that already outperformed other proposed systems. Technical challenges in the pharmacy field and corresponding solutions were also illustrated using the example robot developed during this ongoing project. Further challenges and future endeavors to realize the intelligent robot-integrated pharmacy systems were presented along with experimental results based on a simple software implementation.

12.1. Successful AI Integration in Community Pharmacies

The pharmaceutical sector has been among the sectors that AI was traditionally not considered to be useful in. The advent of advanced pharmacy systems changed the traditional model of the pharmacy exponentially. The integration of dispensing devices with advanced pharmacy systems necessitates another level of patient safety in the patients. Not only medication dispensing but the development of chronic disease therapy has been considered in addition to dispense safety. Robot pharmaceuticals consist of high dispensers that are able to release tablets and capsules in blister and foil forms, respectively (R Alahmari et al., 2022). In addition, a pharmacy dispenser robot has also been developed as a cash dispenser, able to dispense medications through a dispensing software embedded in tablets. Integration with the pharmacy system provides map making with unique dispensing software. Successful integration of dispensing robots with pharmacy systems for dispensing at community pharmacies.

The dispensing robot, MedeNaut robotic pharmacy, consists of a medicine input, a medicine dispensing and storage unit, and a control unit connected to the pharmacy’s transaction

Power System Technology
ISSN:1000-3673
Received: 06-01-2025 Revised: 15-02-2025 Accepted: 10-03-2025

applications. Almost all of the configuration methods of the dispensing robot are simple and common for other dispensing robots. The dispensing robot receives prescriptions to dispense medicine dispensing by a unique fixed identifier for each medication with a number of medicine dispensing counts from blister robots. The dispensing software can be installed in either the pharmacy server or the pharmacy-wide transmitter and reporting units. The hotspot for the pharmacy controller issues a signal for searching for the transmitter unit (TU) for each transmitting unit. Configuration for transmitting units is implemented on the pharmacy server by a POI configuration window. Search for dispenser candidates on the pharmacy server is also implemented as in the transmitter units. Mapping, which means cam codes and coordinates, is collected from the corresponding dispensing robots by sending picture files through the control server configuration. This method requires additional effort in reconfiguration when parts of configurational data are changed; however, it enables override of cache mechanisms for prevention of dispensing robot traffic congestion.

12.2. AI in Hospital Pharmacy Settings

AI is widely deployed in drug dispensing systems in hospital pharmacy departments, from dispensing medication orders to preparing unit doses. In automated dispensing machines, AI is used for recording patient information and storing pre-packaged unit-dose medications. Although AI is not involved in packaging bulk forms, dispensing software employs drug databases and calculation rules to provide drug information based on received orders. Therefore, AI is becoming important in pharmacy departments as well as outpatient and inpatient settings. Errors in drug dispensing can occur in any pharmacy preparation unit. In hospital pharmacy departments, medication orders from physicians are received and verified by pharmacists prior to dispensing. Errors in origination, documentation, transcription, and calculation of a medication order are not visible to pharmacy staff anticipating medication dispensing. In large hospitals, orders of more than 50 medications per day are not rare, making it difficult to review orders completely without missing deviant ones. A medication ordering support system that finds and highlights potentially erroneous medication orders was developed using a hybrid machine learning model.

In every hospital, dispensing and supply of medications are critical processes for patient safety. Errors in drug dispensing procedures may incur adverse effects on patients' health and healthcare costs. Assessing the potentials of machine learning models in drug dispensation in pharmacy departments, this research developed a novel approach based on a hybrid ensemble machine learning model that employs a combination of decision trees, extreme gradient boosting, random forests, logistic regression, and support vector machines for producing and validating models in order to automate screening medications ordered in clinical settings. With pre-developed criteria, the ensemble model was trained using thousands of medication order data over a five-month period in the post-feasibility test. Developed models were

Power System Technology
ISSN:1000-3673
Received: 06-01-2025 Revised: 15-02-2025 Accepted: 10-03-2025

continuously assessed and fine-tuned by keeping an eye on false alarm rates. An early screening support system was built using the developed model to assist pharmacists during medication order verification prior to drug dispensing, helping shape it as clinically useful.

AI is the simulation of human intelligence processes by computer systems. This term can refer to any human-like actions as well as computers that can think like humans. On the scientific side, AI refers to a field of computer science that attempts to understand and reproduce human behaviors. On a broader side, it refers to systems that can converse with people and have knowledge grounds. These systems aim to perform tasks or respond in ways that human-like senders would do. AI makes leveraging various states of knowledge necessary as knowledge is one of the most important factors affecting a sender's outputs. Knowledge is the set of facts, information, and skills acquired by a person through experience or education. Knowledge areas are domains consisting of knowledge within specific fields.

13. Challenges and Limitations of AI in Pharmacy

In recent years, the pharmacy sector has gradually seen drastic changes originating from the development of computerized and robot technologies. Within the field of AI, a significant new technology, which has shown its effectiveness in various fields, is presently being investigated to increase the safety and precision of pharmacy practice. For example, computerized advents are used to detect the generated errors in conventional medication dispensing practices (R Alahmari et al., 2022). Although this emerging technology has shown an extensive capacity to provide further accuracy and safety comparing to the previous generations, it has still been plagued with a variety of difficulties and obstacles in terms of patient safety and its accompanying problems.

It was demonstrated that AI could help pharmacists in a variety of clinical and operational routines, such as drug selection, genetic drug screening, image recognition, prescription validation, therapeutic drug monitoring, inventory management, informing procedural workflows, address error prediction, adverse drug reactions prevention, enhanced pharmacy productivity, and recommendation of therapeutic alternatives and similar medications. However, there are also constraints for AI to enter into the domain of pharmacy practice such as poor patient and physician awareness of AI technologies, non-publicly available databases for training, a lack of clinical and regulatory guidelines, and prevailing legal principles for computerized decision making. Scrutinizing the advantages and drawbacks of using AI technologies into pharmacy practice forms the foundation for breaking down its observed discrepancies.

14. Future Trends in AI and Pharmacy

As AI and pharmacy rapidly evolve, significant technological advancements promise to reshape how medicinal substances are developed, manufactured, and distributed. In drug

Received: 06-01-2025 *Revised: 15-02-2025* *Accepted: 10-03-2025*

discovery, knowledge-based AI, ML algorithms, molecular modeling and docking, and other bioinformatics tools could facilitate screening and predictive modeling of ADMET properties and protein-ligand interactions. Generative methods could generate new drug-like compounds, revolutionizing drug discovery processes. In integrated development, AI technology could enable self-optimizing drug formulation and consciousness on process performance and quality assurance. In design and in silico bootstrapping, digital twins, mechanistic models, and knowledge-based AI could help design devices for pharmacy care upper-airway disorders and complex treatments involving multiple human organs. Model-based computation of biopharmaceutical formulations could ensure patient safety and efficacy, while adaptive and reinforcement learning could govern real-time regulation of adjustable data acquisition and formulation-design parameters. Data-driven learning and smart optimization approaches could lead to more compact and smarter processes enabling real-time assessment of product quality in manufacturing processes based on real-time release testing and risk assessment. Integration of surgery, robotic, remote-controlled adjunct devices, and computer-based virtual paradigms could lead to smarter clinical and pharmacy care, encompassing integrated advanced HD devices for foetal surgery and personalized medication and robotic assistance. A&AI technology could facilitate various iterations of complex drug dose/delivery administration. In use diagnostic rule unpublished backgrounds and therapeutic applications, as AI-based advisory and prevention tools, enable pharmacy counsels and universal vaccination and therapy rules. Thus, developing new relationships with scientific humanists, field experts, and manufacturers/stakeholders would be vital to realizing the full potential and ensuring patient safety and regulatory compliance with hallucinating AI (Ioana Visan & Negut, 2024).

15. Training and Education for Pharmacists

Incorporating education on Artificial Intelligence (AI) in pharmacy schools is essential to prepare students for the evolving role of technology in the pharmacy profession. Despite rapid advancements in AI, pharmacy training needs to catch up to ensure that students are adequately prepared. Using a nationally validated questionnaire, a convenient sampling strategy was employed to recruit participants. Knowledge, attitude, practice (KAP), and required curriculum elements regarding AI were evaluated using 5-point Likert-scale statements. Factor analysis was utilized to group related items. (E. Hasan et al., 2024).

Due to the rapidly evolving field of artificial intelligence (AI), which is transforming many aspects of public life, including health care and drug dispensing, training in AI and technology is essential for pharmacy graduates and pharmacy technicians. An important question for both organizations is how to educate current and future pharmacists about AI and its implication for pharmacy practice, health care, and the public. Pharmacy education will also need to consider how the broad issues of transparency, accountability, and governance

Power System Technology
ISSN:1000-3673
Received: 06-01-2025 *Revised: 15-02-2025* *Accepted: 10-03-2025*

will be considered in the pharmacy profession as AI technology develops. Significant issues include equity of access to care, patient safety, and how bias in data sets used to train AI systems will be avoided or minimized to prevent health inequities and loss of public trust.

16. Collaboration Between AI Developers and Pharmacists

The integration of AI into current pharmacy practice requires a collaborative approach with pharmacy organizations worldwide. This collaboration can help address concerns about safety and efficacy. AI developers will need to work with regulations and licensing boards in various countries, just as pharmaceutical companies do to develop prescription drugs (Singh et al., 2023). Such regulations must be adapted for AI tools. Development is only the first step in addressing concerns; developers must also actively work with the pharmacy profession offering their service. This may include providing information on how AI systems are being trained, how they work, clarifying any black box approaches, and ongoing secondary monitoring of the AI service to ensure its efficacy and prevent algorithm drift (Ioana Visan & Negut, 2024). Lobbying boards and regulators may also be needed to protect organizations from liability should an AI decision lead to harm.

Another area of collaboration for professional organizations is in development of training and education resources and programs for pharmacy schools, other health professions education programs and practicing pharmacists that would help build the digital health literacy of pharmacists, their ability to assist patients in effectively using such technologies, and ways to work with developers and regulators to foster maximum safe and effective use of non-prescription AI. Such education would embrace the full breadth of AI in healthcare, ensuring pharmacists well understand the technologies involved and AI literacy in dealing with patients and facilitating human-centered application of AI. Front-line provision of this education would align with the pharmacy profession’s commitment to lifelong education and the limits of training resources at school and faculty level.

17. Impact of AI on Pharmacy Workforce

Artificial intelligence (AI) is the ability of a system, mostly computers, to act intelligently and perform tasks that would normally require human intervention. AI can be applied in various domains, e.g., science, marketing, cooking, health care, enforcement, research, gaming, etc. Some daily applications of AI involve virtual assistance, chatbots, recommendation systems, etc. Questions about AI usually take the form of “Can a machine ...?” In the pharmaceutical domain, AI can be employed in different applications. Pharmacology refers to the chemicals used in the treatment of illness and disease. It encompasses countless compounds found in nature, or made synthetically, but only a limited number are of therapeutic value. Artificial intelligence refers to computer systems used to perform tasks that usually require “intelligence” (R Alahmari et al., 2022). AI can be

Power System Technology
ISSN:1000-3673
Received: 06-01-2025 Revised: 15-02-2025 Accepted: 10-03-2025

implemented as expert systems. Such expert systems help to sort and distribute medications to patients—using physical robots to dispense medications to patients safely, quickly, and at affordable price ranges, while pharmacists concentrate on more value-adding services such as counseling and education. Although these systems are currently used only in a few hospitals, they have great potential to improve health care in Saudi Arabia.

A robot is considered an intelligent agent, either virtually or mechanically, that can carry out specific qualitative and quantitative tasks under supervision or automatically. A robot can include sensing (acquisition of information about an environment via sensors), reasoning (integration of information for interpretation) and decision-making (selecting reasonable actions). The robot can undertake various tasks in environments that are either structured or not without human supervision. Tasks performed by a robot are called robotic applications. In pharmacy, robots are used to automate various tasks to increase effectiveness and efficiency, thus improving employee satisfaction. Robots are used in many sectors because of their reliability, efficiency, and safety. Relevant to this study is the use of robots within the pharmaceutical sector; these robots can be programmed to make the distribution of prescription drugs more effective and efficient, reducing the need for human intervention and the risk of human error. When dispensing medications to patients, organizations should consider the safety and accuracy of dispensing. The significant benefit of incorporating robots in medication distribution within a pharmacy is to dramatically decrease the time, money, and risk of negligence in dispensing medications. The accurate planning of how a robot will enter its environment is vital. Robots use map-making algorithms to create an accurate map of their environments, which is essential for the effectiveness of their application. The accuracy of these maps is important as it forms the basis of the practical applications carried out by the robots.

18. AI in Drug Development and Research

Artificial Intelligence (AI) has found applications in almost every field. In drug discovery, there are almost no limitations to what AI can use as input, whether data is simple or complicated, structured or unstructured. If one can formulate it as a question, AI can solve it. AI can use chemical structure, growth mechanism, protein sequences, clinical manifestations, scientific literature, omics profiles, real-word evidence, and patient characteristics to speed up drug discovery, development, repositioning, and combination processes.

In drug discovery, AI has started to revolutionize target identification, virtual screening, de novo drug discovery, hit-to-lead and lead optimization, ADMET optimization, drug repurposing, and drug combinations (Ioana Visan & Negut, 2024). Various AI models have shown performance improvements over human-designed models, pushing the boundaries of conventional chemical ideas in developing new drugs, drug compositions, and combinations and identifying new disease targets. Before this revolution, there were several physical

Power System Technology
ISSN:1000-3673
Received: 06-01-2025 Revised: 15-02-2025 Accepted: 10-03-2025

mechanisms and rules that narrowed the good chemical space. With the help of AI, there are no such restrictions, and potential efficacious drug candidates have been found at an unprecedented speed that lies out of conventional wisdom. Various commercial and open-source platforms are available for pharmaceutical companies and startups. There are also comprehensive examples and packages of advanced AI techniques across different drug discovery applications. With these technologies, input data, and a computationally equipped server, AI has started to rewrite the drug discovery tradition.

AI has yet to profoundly penetrate the drug delivery landscape, despite being an integral part of drugs. Drugs could not exert therapeutic effects without a carrier, whether oral, parenteral, or other delivery routes (Singh et al., 2023). With the increasing knowledge of drug transporters in biological barriers, nanoparticles, organic devices, and tissue-engineering scaffolds developed by nanotechnology and materials physics, drug delivery systems have also become highly complicated systems. Companies would use observation-based heuristics, like in the case of small-molecule drug design, to develop their highly sophisticated drug delivery systems. To avoid billions of dollars of losses, expansive lags, and intractable complexities, integration of AI is necessary and urgent. AI can be applied to systematically study real-word delivery systems and obstacles, quantitatively model transporters and their interactions, and compute advanced designs of conveyers to make drug delivery efficient and safe.

19. Patient Engagement and AI Tools

In parallel to the rapid transformation in patient safety, there has been a distinct focus on transforming the engagement of existing and potential patients. Digital technologies have enabled patients to increase their levels of engagement with all aspects of the healthcare system. For example, the digitization of easily accessible patient-level data has enabled novel patient-recruitment mechanisms for clinical trials (Singh et al., 2023). In much the same manner as digital technologies are reshaping how consumers interact with services in wholesale and retail markets, they have begun to reshape how patients interact with their health record companies and healthcare providers. The concept of Digital Box-of-Care (Digital BOC) has been proposed to reflect this ongoing revolution in how patients interact and configure their future interactions with the healthcare system. Digital technologies are enabling the emergence of proactive patient engagement approaches where patients are supported in self-monitoring their health and configuring care-pathways. They are also enabling the emergence of novel approaches where patients beyond standard case-trials can be targeted as part of clinical research. Digital BOC is defined as a system that offers patients everything they need to configure their interactions with all aspects of their health and healthcare continuously (Babel et al., 2021).

Power System Technology
ISSN:1000-3673
Received: 06-01-2025 Revised: 15-02-2025 Accepted: 10-03-2025

The Digital BOC reflects a shift from passive patient-management approaches, with the focus on providing emergency room (ER) services, to patient engagement and self-management initiatives enabled by digital technologies. The emergence of real-time data collection technologies is introducing a gradual shift towards proactive healthcare. Digital engagement has great potential to improve health and treatment outcomes by enhancing patient knowledge through health-promoting social networks, collaborative health communities, and shared resources. However, active participation in collaborative care is complex and challenging, as it requires a significant behavioral change for patients. Communication gaps, insufficient health professional knowledge of technology, understanding of information technology, lack of sense of community, facilitators, and patient motivation barriers hinder the translation of new collaborative care initiatives into practice. Machine Learning can enable the effective synthesis of patient-level longitudinal data into patient- and clinical level indicators of the effectiveness of new approaches to both normal and abnormal patient engagement.

20. Global Perspectives on AI in Pharmacy

The integration of artificial intelligence (AI) in pharmacy practice appears irreversible. Rapid developments in AI, chiefly generative AI models, attracted global attention and acceptance. Such technologies hold the potential to revolutionize pharmacy practice and health care services, putting some pharmacists' jobs at risk. Pharmacy educators have a key role in preparing pharmacy graduates for evolving practice environments and addressing AI-related concerns. This study aimed to assess the knowledge, perception, attitude, and practice concerning AI in pharmacy practice in the context of pharmacy students and academic faculty in various countries (E. Hasan et al., 2024).

A survey was developed, and its Face and content validity were tested. The target population included pharmacy students, faculty members, and faculty staff worldwide. The target sample size was 385 responders. Data were analyzed using descriptive and analytical statistics. The study reveals an adequate knowledge of AI applications in pharmacy practice among pharmacy students and faculty members. Yet, their practical and future AI use in education and pharmacy practice hasn't been optimized yet. A majority of participants would like to see AI being integrated into pharmacy curricula. To the best of our knowledge, this is the first multinational study assessing the knowledge, attitude, and practice toward AI in pharmacy education and practice.

The adoption of digital health technologies, including AI, has progressed at a faster rate than pharmacy academics' and workforce preparation. Education for pharmacists varies by country, with different levels of governmental engagement and pharmacy profession involvement. Disparities exist in the inclusion of AI in academic pharmacy curricula, where curricular items may be only partially covered. After recognizing the noteworthy roles of

Power System Technology
ISSN:1000-3673
Received: 06-01-2025 Revised: 15-02-2025 Accepted: 10-03-2025

pharmacy graduates, pharmacy academics have a voice and responsibility to propose and assume action through national and international collaborations, synergies, and networks to lead AI educational efforts within the pharmacy profession.

21. AI and Telepharmacy

Healthcare access is limited in many regions of the world that lack pharmacies, especially in rural areas. Telepharmacy is a solution for these regions. A foundational premise of telepharmacy is its ability to improve access to pharmacy services. For those located far from pharmacies, in low-supply areas, and with flexible clinic hours, telepharmacy is an extremely important and useful option that allows them access to pharmacy services. Furthermore, telepharmacy provides an opportunity for retired pharmacists and pharmacy students to continue to stay involved in the pharmacy profession following mandatory retirement. Telepharmacy is fully capable of improving access to health services in a variety of nations and societies to meet needs around the globe, however societal factors may also affect how telepharmacy is implemented (Edrees et al., 2022). Telepharmacy solves more than just the proximity problem. The cost of a pharmacy's real estate is very high and takes a large investment up front. A compact telepharmacy only needs small quarters and an area to list its name and sign. Thus, there is potential cost savings every month from rent and utilities, funds that can be diverted to providing excellence in services. Telemedicine is also taking off in particular interest areas. More doctors and patients would prefer a video call instead of a proprietary visit, especially for inevitable issues like consults, medication refills, and acute illness questions. It is prudent to anticipate a similar demand from patients on the pharmacy side. There is a definite need for extended pharmacy hours for most traditional pharmacies, especially on weekends. Patients frequently report they desire more options for obtaining medications. Telepharmacies can unburden traditional pharmacies while simultaneously creating new income streams from previously underserved patients. In many cities, the drive to a pharmacy becomes a hefty toll, especially with clogged traffic. A patient may be stuck in a car with a fractious child, running on fumes and a half-eaten granola bar. Telepharmacy puts the pharmacist back in charge of treating that patient by meeting him or her on their terms. Furthermore, tele pharmacies have a new opportunity to soberly optimize pharmacy workflow. Whether due to workplace relationships, dependence on intuitions, or rigid requirements, traditional workflows can be extremely unyielding. Wherever one stand on the degree of leash a tech company should have, one must admit that optimizing computerized workflows is generally more straightforward. This is a hidden opportunity all over healthcare, but it can particularly help in improving medication therapy management workflows.

22. Cost-Effectiveness of AI in Pharmacy

The present study was initiated to evaluate whether AI in the form of a robot providing assistance to pharmacy technicians filling blister packages would result in better financial

Power System Technology
ISSN:1000-3673
Received: 06-01-2025 Revised: 15-02-2025 Accepted: 10-03-2025

outcomes than procedures currently used in the pharmacy; so-called control procedures. The financial figures relevant for the investment proposal were thus expressed in monetary terms. The AI robot is expected to be able to dispense single doses and blister packs with a net profit of 46,805.00 euros from dispensing single doses and an investment payback time of approx. 2.46 years. Including incubator, film and RFID camera, with a maximal purchase price of 585,000 euros, the break-even point for single doses was expected at approx. 5 years and 10 months. For the total investment, net investment in the robot of 619,000 euros, a net gain of approx. 821,000 euros was calculated to equal a payback time of 11 months. Somewhere between these extreme values lies the actual payback time for the total investment (R Alahmari et al., 2022).

The rationale for the entire project was to find financeable solutions to continued patronage of the hospital pharmacy making it possible to safely dispense outpatient medication from standard blister packages, thus protecting patient safety and medication adherence, and freeing pharmacy technician capacity for handling sterile prescription medications. Expected benefits of the proposed AI robotics were expected less human errors when dispensing medication and improved patient safety. A second benefit was expected to be enhanced pharmacy technician capacity to safely dispense sterile prescription medications in high volumes. Along with these benefits were expected socio-economic rationales that could be directly translated into monetary terms.

Still, the inevitable unquantified benefits recommended further research and studies on the impact of the acquired knowledge gaining machine on the remaining pharmacy work routine and stakeholders involved. To support reliable predictions on implementation, knowledge will need to be acquired on how to offer successful change management in terms of the interaction between machines and humans. Not only implementation, but also how to integrate this kind of machine with the work routine and interface will require extended research to support stakeholder understanding and compliance.

23. Evaluation Metrics for AI Systems in Pharmacy

Artificial intelligence (AI) is being extensively applied to every industry nowadays. Artificial Intelligence (AI) can be defined as a system that delivers intelligent results or makes decisions without human intervention. Artificial Intelligence (AI) is defined by (R Alahmari et al., 2022) as the ability of a system to act intelligently and perform tasks that would normally require human intervention. The AI can be defined as the capability of a machine to imitate intelligent human behavior. Pharmacology is defined as the chemicals used in the treatment of illness and disease. Pharmacy can be defined (Graafsma et al., 2024) as a profession engages in the continual licensing and advice of upon preparation, properties, effects, usages, and the uses of chemical. Robots can be defined as semi-autonomous and autonomous machines composed of mechanical systems controlled by computers. A robot is

Power System Technology
ISSN:1000-3673
Received: 06-01-2025 Revised: 15-02-2025 Accepted: 10-03-2025

considered an intelligent agent that can carry out tasks under supervision or automatically. Robots can be classified into two categories: industrial and service robots. Industrial robots are conventional robots and controlled by a microcontroller through a motor driver. The industrial robots are usually thick and cumbersome. These robots are focused on mechanical work. Service robots are highly mobile as compared to industrial robots. The service robots include delivery robots and these robots are developed to carry out various tasks such as moving from one place to another and providing services. The robots can transport materials have intelligence to comprehend the environment around them and can be controlled over the network. Service robots rely on advanced AI algorithms, sensors, and networks to provide efficient services.

Medicines and pharmaceuticals are classified as either over-the-counter (OTC) or prescription drugs, based on safety and effectiveness. The OTC drugs can be dispensed over the counter without a doctor’s prescription and the prescription medicines are dispensed with a prescription written by a licensed physician. Most products being sold in a pharmacy store are prescribed medicines. Before dispensing prescription medicine, pharmacists must verify the authenticity of the prescription entered into the system and check for any potential medicine interactions. It is labor-intensive and if more than one pharmacist is engaged, the verification process becomes delayed. The pharmacy risk of litigation is amplified if there is a mistake made in filling prescriptions. A system must be developed that evaluates the case of the physician-prescribed drug and issues alerts to the pharmacist in the form of potential interactions between the current prescription drug and the previously administered drugs.

24. Interdisciplinary Approaches to AI in Pharmacy

Artificial Intelligence (AI) is a rapidly developing area in pharmacy, providing solutions to improve the accuracy of drug dispensing and the safety of patients. Robotics and AI are tools to increase the capability of pharmacist manpower. AI is transforming pharmacy practice all over the world. From prescribed medicines to produced medicines or from clinical decision-making to surveillance and reporting, many facets of pharmacy practice are being revamped with the latest technological innovations. Some aspects of pharmacy practice have been already automated deeply and widely, while others are still at the beginning dimension and need proper research, analysis, and verification. Therefore, an upcoming revolution in the pharmacy sector is inevitable.

Random dudes with unverified AI applications instantly become pharmacists, posing threats to public health and welfare. But there are still a few crucial areas of pharmacy practice where AI is being used. Whether it is drug dispensing using AI and robots or screening for drug-target interaction in novel molecule designing, approaches spanning the different disciplines converge and find commonly inferences. Many bioinformatics approaches used to determine drug-target interactions have a machine learning backend. Most big discoveries in

Power System Technology
ISSN:1000-3673
Received: 06-01-2025 Revised: 15-02-2025 Accepted: 10-03-2025

drugs coming from the pharmaceutical industry are often imitated in silico. Applications like AutoDock or Molecular Dynamics Simulation are there to provide the solution domain whether the designed compounds bind to the target site, or their docking score. This kind of simulation is there in new chemical entities. There are now many available deep learning models trained on chemoinformatic features to predict drug-target interaction. However, professional researchers do this for new drug discovery at the laboratory, but AI can help here to screen out the probable candidates either drug or disease targets using computational approaches.

It is a multi-wise area since many backgrounds like chemistry, bioinformatics, and computational biology are converging in it. The latest developments in deep learning, i.e, GNNs or GATs, are revolutionizing this field (Singh et al., 2023). The field of drug delivery is like a black box in which many pan-layers of drug formulation are there. Considerable efforts have been made to model this bio- nano processing area. Efforts have been made using deep learning models to predict fifty different oral dosage forms, six distinct routes of administration, and target organs with non-oncological applications. This offered plenty of applications with global reach for patients, doctors, and the pharmaceutical industry (Ioana Visan & Negut, 2024).

25. Conclusion

Artificial Intelligence is reshaping several industries. In recent years, AI has significantly impacted the healthcare sector with the development of algorithms and sophisticated machine learning applications. The objective of the current mini-review paper is to cover the published literature reporting on pharmacy robot technology as one of the most important applications of AI in pharmacology. The exploratory search process covered the most relevant organizations in the pharmacology community. These search results were screened and filtered to include studies that reported an outcome measure related to the technology of the robot pharmacy. Publications in English that were published from 2010 to date were included. An estimated 30 million pharmacy errors occur annually—about 1.5 million errors per year in hospitals—leading to approximately 7,000 patient deaths and thousands of severe complications each year. Among the contributory factors for such errors, 'overworked pharmacy employees' were reported by 96% of respondents. The increasing number of prescriptions reduces the time staff can use to focus on each prescription. The most common pharmacy errors include the incorrect dispensing of medications (e.g., wrong medication, incorrect drug form, etc.) and incorrect dosage administration (e.g., incorrect dosage, frequency, route of administration, etc.). The need for robotic-assisted pharmacies arise to reduce human error. The possible pharmacy tasks that may be performed by robots include medication preparation, dispensing unit dose blistering, 24-h medication distribution, dispensing of dinner trays and protein shakes, etc. The advantages of robotics in pharmacy

Power System Technology
ISSN:1000-3673
Received: 06-01-2025 Revised: 15-02-2025 Accepted: 10-03-2025

include improved patient care, increased revenue, enhanced productivity, decreased patient waiting time, adding flexibility to reduce the workload on employees, etc. Using barcoding and photo verification increases patient safety and decreases the risk of litigation (R Alahmari et al., 2022).

References:

1. R Alahmari, A., K Alrabghi, K., & M Dighriri, I. (2022). An Overview of the Current State and Perspectives of Pharmacy Robot and Medication Dispensing Technology. ncbi.nlm.nih.gov
2. Ioana Visan, A. & Negut, I. (2024). Integrating Artificial Intelligence for Drug Discovery in the Context of Revolutionizing Drug Delivery. ncbi.nlm.nih.gov
3. Singh, S., Kumar, R., Payra, S., & K Singh, S. (2023). Artificial Intelligence and Machine Learning in Pharmacological Research: Bridging the Gap Between Data and Drug Discovery. ncbi.nlm.nih.gov
4. Han, Y. & Tao, J. (2024). Revolutionizing Pharma: Unveiling the AI and LLM Trends in the Pharmaceutical Industry. [PDF]
5. E. Hasan, H., Jaber, D., Al Tabbah, S., Lawand, N., A. Habib, H., & M. Farahat, N. (2024). Knowledge, attitude and practice among pharmacy students and faculty members towards artificial intelligence in pharmacy practice: A multinational cross-sectional study. ncbi.nlm.nih.gov
6. Babel, A., Taneja, R., Mondello Malvestiti, F., Monaco, A., & Donde, S. (2021). Artificial Intelligence Solutions to Increase Medication Adherence in Patients With Non-communicable Diseases. ncbi.nlm.nih.gov
7. Edrees, H., Song, W., Syrowatka, A., Simona, A., G. Amato, M., & W. Bates, D. (2022). Intelligent Telehealth in Pharmacovigilance: A Future Perspective. ncbi.nlm.nih.gov
8. Graafsma, J., M Murphy, R., M W van de Garde, E., Karapinar-Çarkit, F., J Derijks, H., H L Hoge, R., E Klopotowska, J., & M L A van den Bemt, P. (2024). The use of artificial intelligence to optimize medication alerts generated by clinical decision support systems: a scoping review. ncbi.nlm.nih.gov