REVIEW ARTICLE

Recent Advances in Artificial Intelligence Applications in Pharmacy Practice

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Abstract

The health-care industry is only one of several that has benefited from the revolutionary technology known as artificial intelligence (AI). AI might greatly enhance pharmaceutical practice by better-managing medications and patient care. Several AI applications in pharmacy practice are examined in this study. Using AI technology, chemists are equipped with methods and tools that enable them to make clinical judgments based on reliable evidence. Pharmacists can now analyze vast amounts of patient data, such as medical records, laboratory results, and medication profiles, with the help of AI algorithms and machine learning. This allows them to better assess the safety and effectiveness of medications, identify possible drug-drug interactions (DDIs), and make recommendations based on patient needs. Predicting and detecting adverse drug events, automating dispensing processes in community pharmacies, optimizing medication dosages, detecting DDIs, improving adherence through smart technologies, detecting and preventing medication errors, providing medication therapy management services, and supporting telemedicine initiatives are all possible with the help of specific AI models. Integrating AI into clinical practice allows health-care providers to enhance patient care through personalized decision-making. Various health-care services offered to a single patient may work together more effectively with the help of AI. When it comes to medication, AI could help patients remember to take their medication at the right times, educate them on the importance of taking their medication as prescribed, and increase the likelihood that they will take their medication as prescribed. AI could also help patients find the most affordable health-care options, improve their communication with health-care providers, optimize their health monitoring with wearable devices, offer guidance on healthy lifestyle choices every day, and even incorporate exercise and diet into their treatment plans.

Key words: Artificial intelligence, deep learning, industry, integration, machine learning, pharmacy practice

INTRODUCTION

The precise nature of artificial intelligence (AI) is still up for debate, but one possible description is a computer program that mimics human intellect by mimicking human behavior and mental processes.[1] One branch of AI is known as machine learning (ML), and it entails teaching an algorithm or model to conclude given data.[2] Several intriguing real-world examples show the various possible applications of AI in industrial and therapeutic contexts. On the other hand, health-care curricula also need more

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instruction on AI due to the proliferation of these technologies. As the COVID-19 epidemic has unquestionably intensified, the digital health business has been seeing phenomenal growth. Both "digital health" and "artificial intelligence" have entered the vernacular of the general public and the medical community alike. Chemists must be engaged in the growing use of these technologies in health-care settings.[3]

Patients often interact with chemists because of their position as frontline health-care providers. Digital health is rapidly becoming an essential part of managing chronic diseases. Pharmacists are vital in using technology to enhance patient experiences and results, whether its monitoring symptoms, tracking adherence, or even the administration of treatment itself. There has to be a stronger emphasis on AI in pharmacy curricula, and pharmacists should have a say in how these algorithms are designed and implemented. Another thing chemists may do is spark interest in AI among their students and fellow pharmacist colleagues.[4]

From hospitals to primary care clinics and even patients' homes, chemists are the go-to specialists when it comes to drugs and can assist patients choose the best course of treatment. To provide a solid foundation for critical thinking in patient work-up, chemists undertake extensive training. Due to the prevalence of AI in digital health technologies, it will be necessary for chemists to use their existing knowledge to assess these algorithms. There seems to be little rush to include chemists as important players, even if many AI clinical applications are still in the proof-of-concept phase. This article will provide a synopsis of the current AI uses within the pharmacy setting and talk about ways in which pharmacists may become involved.[5]

To aid those suffering from chronic kidney disease (CKD), another business, Cricket Health, uses ML. Without laboratory results, the Cricket Health models can estimate the glomerular filtration rate. With 37 people taking part in the intervention group out of a total of 61, the Cricket Health educational program served as the basis for a cohort study. The findings of the survey showed that a higher number of patients enrolled in the Cricket Health program began dialysis in an outpatient setting and exhibited superior illness awareness ($P < 0.001$).[5]

In a different, related research with Cricket Health, patients in stages 4 and 5 of CKD were educated on the many treatment options available to them so that they may make an informed decision about their renal health. Compared to conservative therapy, patients' understanding of their illness condition improved, and they were more likely to choose peritoneal dialysis and kidney transplants.[6]

Community pharmacies have also adopted clinical decision support systems (CDSSs). A literature analysis including six trials demonstrated a decrease in the incidence of unsuitable drugs for pregnant or elderly patients and a reduction of 31% in drug–drug interactions (DDIs). Clinical inertia and alert fatigue were identified as obstacles to the implementation of CDSS in the community context, according to the research.[7]

Ambulatory care settings also make use of AI. Using data from sixteen separate trials, researchers conducted a systematic review of CDSS in patients who needed anticoagulation. The CDSS had many advantages, such as the ability to integrate with electronic medical records (EMRs), the fact that clinicians did not have to enter any more data, and the fact that it offered suggestions instead of just evaluations. The lack of formalized incentives to use the technology, failure to communicate decision-support outcomes to patients, and lack of frequent feedback to physicians are some of the negative aspects of CDSS that the research highlighted. These issues might potentially hinder the use of CDSS in practice.[8]

The research presents an acute care hospital that uses CDSS to drive pharmacy actions in antimicrobial stewardship, highlighting the potential benefits of AI for pharmacists in this scenario. Among these treatments were the following: optimization of doses, conversions from intravenous to oral administration, de-escalation of antibiotic regimens, and detection of unsuitable medications using patient laboratory data or cultures. Diabetes educators were notified through the CDSS of any unusual blood glucose readings in the patient's medical records, according to the authors. Consequently, chemists' clinical interventions rose by more than 100% monthly and saved over $1.5 million per year when they used the CDSS.[9] Figure 1 depicts the AI applications in Pharmacy Practice and allied sectors.

INDUSTRY APPLICATIONS

The current approximate cost of developing a novel treatment is $3 billion, and the projected development time is 10–15 years. When used in conjunction with *in silico* models, AI and related techniques (such as ML or deep learning [DL] [Figure 2]) can forecast a wide variety of physicochemical properties, pharmacokinetic features, selectivity, and more, allowing R&D teams to zero in on preclinical candidate compounds with the potential for higher yields. Pattern recognition is another area that has found usage for deep neural networks (DNN), which has the potential to benefit the fields of pharmacology and drug development. Using these DNNs, we may generate new attributes for the compounds that go beyond their conventional molecular structure. The optimization of DNN algorithms in health-care contexts, however, will need substantial investment when these algorithms gain widespread use.[10]

Drug design may benefit from AI by employing 3D architectures to validate protein targets. There is some curiosity in applying AI to this, but thus far, it has proven to be both costly and labor-intensive. Nevertheless, target prediction has made progress when DL approaches are combined with other neural networks. It is also feasible to use AI to predict protein–protein interactions. Because this

Figure 1: Artificial intelligence applications in pharmacy practice and allied sectors

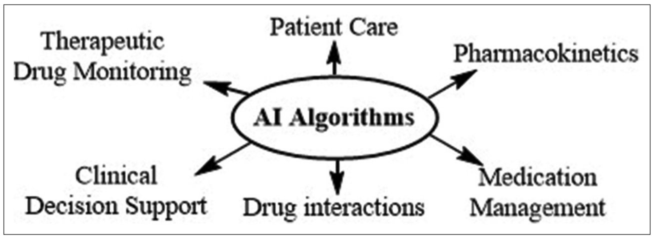

Figure 2: Role of artificial intelligence in pharmacy practice

approach makes the drug's target profile more selective, it may even lower the risk of adverse events in small-molecule medications. In addition, neural networks may be used early in the drug development process to detect ADME outcomes of the researched molecule-disease state combination.[11]

AI is also used in medication repurposing and "hit discovery" to build disease state models that are then tested against chemical libraries, some of which are private (like GOSTAR) and others of which are public (such as ChEMBL and PubChem).[12] A well-optimized, non-biased dataset may be used to construct drug repurposing models utilizing ML and DL algorithms. To further find the optimal treatment candidate according to the illness state, these models are employed in combination with the chemical libraries indicated before, with human direction.[13] The duration of preclinical testing has been shortened using these drug models, which were first employed for early screening. One medication that targets OCD, DSP-1181, was co-developed by Exscientia and Sumitomo Dainippon Pharma. On average, it takes around 12 months from the beginning of screening to the conclusion of preclinical testing, while the industry average is 4–6 years.[14]

If they want to succeed in either the clinical or business worlds of AI, chemists need the resources and education to grasp the basics. Hence, training should be prioritized through means such as digital health research, continuing education (CE) for pharmacists, and curricular enhancements to pharmacy schools.[15]

AI IN PHARMACY PRACTICE

There has to be a shift in health-care education to reflect the increasing use of digital health in both clinical and industrial settings. Digital health education for chemists should be more widely available so that AI may be more easily integrated into current practice settings. Elective courses, educational tracks, minors, or certificate programs might strengthen digital health training, and incorporating digital health into the pharmacy school curriculum could be one way to achieve this goal.[16] Master's degrees, fellowships, residencies, and CE credits are all examples of postgraduate possibilities. Few training methods now exist, especially ones using AI, according to a comprehensive curriculum search across the United States pharmacy schools. A large void in formal education possibilities persists, despite the development of several digital health fellowships and permanent positions at prestigious institutions, such as USC and UCSD.[17]

The community saw the publication of a detailed study on a Global Digital Health Education Framework by the International Pharmaceutical Federation (FIP). Using a survey to identify existing possibilities, this research showcases worldwide projects that incorporate digital health into pharmacy education and the pharmacy profession. It is the first of its kind.[18]

The survey's main results, which indicated that only a small percentage of pharmacy schools provide digital health teaching, were similar to those of the US syllabus search. It also discovered that several survey takers erred by thinking that the phrases "online education" and "digital health education" were synonymous. Offering digital health education was hindered by a lack of resources and specialists to assist with implementation. Regardless of these results, a positive trend emerged: Almost half of the participants thought their school could adapt to new digital health technologies as they came out and that their students would be ready to provide digital health services.[19]

Deficiencies in pharmaceutical workers' understanding and competence were brought to light by this report's conclusions. Despite participants' evident desire to understand how to employ this technology for clinical issue solving, one of the least probable themes taught in pharmacy education was the implementation of digital health technologies in clinical care. In addition, several participants highlighted the potential benefits of digital health technologies, such as AI and ML for enhancing health-care accessibility, quality, and results.[20] Despite a lesser baseline knowledge compared to the more widely discussed issues such as electronic health records (EHRs) and e-prescribing, participants were most interested in topics such as AI, chatbots, and blockchain technology. The research found that data interpretation and the uses of AI in clinical pharmacy and industrial contexts seem to be significant gaps in digital health training and education. Currently, the focus is largely on operational and administrative capabilities rather than AI and ML [Figure 3].[21]

Digital health training possibilities have been effectively implemented by a small number of institutions. Students

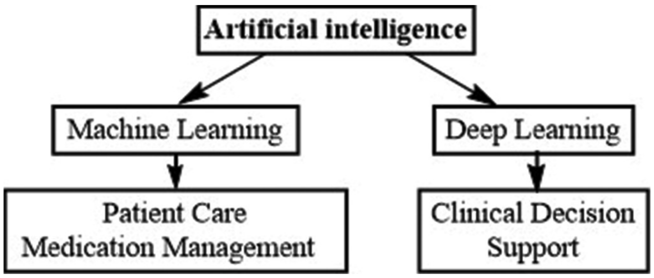

Figure 3: Role of artificial intelligence, machine learning, and deep learning in pharmacy practice

interested in digital health were asked to apply to a pilot optional course at Utrecht University in the Netherlands. Through engaging seminars, guest lecturers, and practical tasks, students were able to acquire a varied understanding of AI, chatbots, blockchain, and other related subjects. Another case study looks at a digital health postgraduate program in Madrid, Spain. The program taught students how to use AI and other digital technologies to better understand how information technology may lead to patient-centered care.[22] An ongoing model of La Trobe University's vertically linked digital health curriculum, which is incorporated into their present pharmacy program, was noted. The university is located in Australia. Students have been able to lay the groundwork for their future success using this layered approach beginning in their 1st year. Later on, they show how digital technologies may improve their practice by expanding on it and applying it to current treatment cases and clinical examination role-plays. By delving into more intricate subjects such as AI, big data, and robots, they get a more profound comprehension. Students may learn to be innovative in their future practice environments by keeping an open mind regarding the practical applications of subjects like AI, as seen in these instances.[23]

In the traditional model of pharmacy education, students learn the ropes by doing things, such as completing a comprehensive drug history, comparing and contrasting prescription lists from different sources, and educating patients thoroughly. With the health-care system becoming digital and chemists taking on new responsibilities, there has to be an effort to measure digital health literacy and gather data on non-medication treatments that use digital technology. "Digital health" will essentially mean "health" in the age of digital transformation, according to Timothy Aungst.[24]

AI INTEGRATION IN PHARMACY PRACTICE

Certainly, AI will eventually be used in pharmaceutical practice. Pharmacists must grasp AI ideas to adapt to the demands of the future. Pharmacists may be better equipped to care for their patients with the use of AI-generated clinical decision assistance. If chemists can understand and use the algorithmic data, they will be in a prime position to lead the way in creating patient-centered treatment. Nonetheless, health-care delivery is evolving, and educational standards must as well. Based on survey results, it seems that chemists do not get much, if any, formal training in the use of AI in clinical decision-making or evidence-based medicine.[25]

As a means of continuing their experiential education during the COVID-19 epidemic, students have been adjusting to precepting methods and virtual patient care practices. In the post-COVID age, educators should embrace a digital health competence framework and chemists should use digital services beyond telehealth visits. The medical field has a history of being slow to embrace new technology. Incorporating digital health education – particularly in AI, ML, and digital medicine – into pharmacy curricula is crucial, according to the FIP research. In addition to incorporating digital capabilities into the curriculum for the next generations of pharmacists, CE, and professional development training in developing digital technologies should be prioritized to help working pharmacists.[26] Figure 4 describes the integration of AI, ML, and DL in the context of pharmacy practice.

RECENT RESEARCH FINDINGS

To study how EHRs affected medication mistakes, researchers studied using a quasi-experimental time series approach. We looked back at data from 1.5 years before and after we implemented EHRs. Throughout the research site, several units contributed to the data that was analyzed. The quality department's risk management branch supplied the data on medication errors. The method of drug management was examined through a qualitative lens. The numerical data were analyzed using descriptive and inferential statistics. The results showed that there was a significant decrease in the median amount of pharmaceutical orders per patient, going from 22.76 before EHR deployment to 18.76 after ($P < 0.001$). On the other hand, the median number of occurrences per patient increased significantly from 0.029 before to 0.040 post-implementation ($P = 0.004$). To further understand these changes, we conducted a qualitative study of the drug management process.[27]

Currently, researchers in Japan are analyzing how automated dispensing robots have changed the drug distribution process. Researchers aimed to assess their effects as well as those of collaborative efforts with pharmacy support personnel. After incorporating the robotic dispensing system, our results showed a significant decrease in the total rate of prevented dispensing mistakes, going from 0.204% to 0.044% ($P < 0.001$). Not only that, there was a significant decrease from 0.015% to 0.002% ($P < 0.001$) in the overall rate of non-forested dispensing mistakes. Negligible occurrences of the erroneous medicine or dose, which have devastating effects on patients' health, were almost eliminated. In addition, there was a substantial decrease, from 60 to 23 s ($P < 0.001$), in the median amount of time that pharmacists spent issuing each prescription.[28]

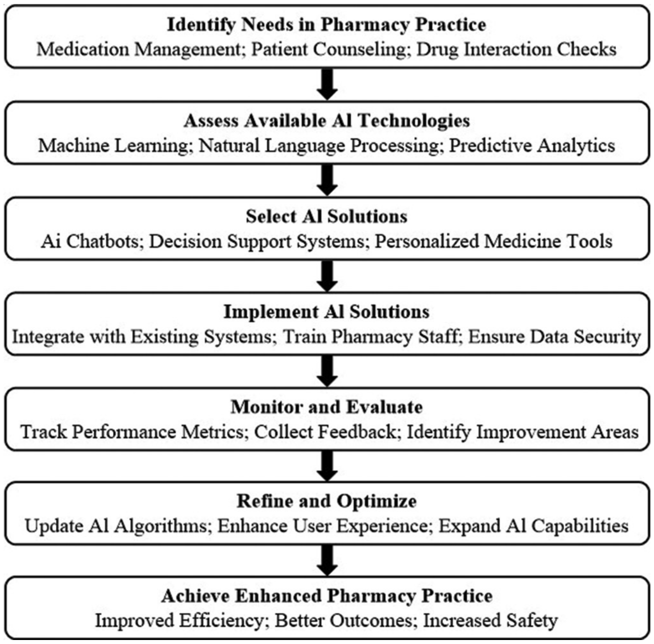

Figure 4: Illustrations on integration of artificial intelligence, machine learning, and deep learning in pharmacy practice

To assess factors including pharmacist productivity, patient wait times for medicine dispensing, and the rate of dispensing mistakes per 1000 prescriptions, researchers collected data continuously in the field for 11 months before implementation. The authors monitored these variables monthly after making adjustments. By the 9th month, improvements were seen in every area. There was a 53% decrease in patient wait time. As compared to the previous year, patient satisfaction with pharmacy wait times increased by 20%. There was a 22% improvement in overall patient satisfaction with pharmacy services. There was a 33% uptick in our chemists' output. In addition, there was a reported absence of dispensing mistakes, indicating a complete absence of error rates.[29]

In an article, the authors discussed how hospital pharmacies might benefit from integrating Big Data, AI, and NLP. Medication safety, therapeutic outcomes, and pharmacokinetic consultations may be greatly enhanced by analyzing unstructured data from EHRs using natural language processing and ML, as emphasized by the authors. They argue that these methods might improve patient care, help therapeutics and pharmacy committees make better decisions, and make it easier to evaluate the effectiveness and safety of drugs in realtime. To improve patient care and medication safety, as well as to find new research questions, the authors also highlight the need to access and analyze the massive amounts of clinical data generated in hospital pharmacy settings.[30]

Research comparing pre- and post-implementation phases was conducted in 2018 to assess medication mistakes using a covert observation approach. Indicators of stock management and employee happiness were also monitored in the study. Technicians used a barcode-controlled system to manually distribute medications before the implementation phase, however, during the implementation phase, the ROWA Vmax (ARX) dispensing robot was used.[31] Manual dispensing was still necessary for some medications, however, because of certain constraints. Reduced prescription dispensing errors from 1.31% to 0.63% (RRR of 51.7%; 95% confidence intervals [CI], 17.3% to 71.8%) were the findings. The error rate dropped even lower to 0.12% (RRR, 90.8%; 95% CI, 70.4% to 97.1%) when mistakes were removed from residual manual dispensing results. In addition, the stock-out ratio dropped from 0.85% to 0.17% (RRR, 80.5%; 95% CI, 49.5% to 92.5%). The median amount of time spent managing inventory by employees each day fell from 1 h and 36 min to 39 min, a decrease of 59.3%. Staff members were generally pleased with the technology, with chemists being somewhat more so than technicians.[32]

IMPACT ON THE CORE RESPONSIBILITIES OF PHARMACY PRACTICE

There is a shift in the way patients, physicians, and other medical staff interact as a result of telepharmacy and other forms of online pharmacy activities. Medication safety, and more specifically the role of pharmacy in the dynamic health-care system, will be affected by the new possibilities and dangers brought about by the digital revolution. In addition, AI will be useful since it can help keep an eye on patients even when medical staff are not there (i.e., chatbots).[33]

AI will greatly aid in diagnosis with its extensive database, but in treatment (especially medication therapy), options and schemes will be organized hierarchically. Since they must remain close to the patient, they may not be directly involved in choices about medical care. However, AI and robotics will also progress. On the other hand, AI can significantly impact clinical practice by identifying and implementing meaningful patterns that can guide chemists' choices. This might be the area where AI has the most impact on clinical pharmacy. The software might 1 day be able to identify and notify when a prescription medicine seems to diverge from its pattern of suitable usage using AI and a significant amount of EHR data to understand patterns surrounding proper medication use. Furthermore, AI might be useful for medication selection by showing which people are less likely to have side effects from a certain prescription based on automated categorization.[34]

The clinical treatment of narrow therapeutic index medications often involves Medication Therapy treatment and pharmacokinetic-guided dosing. In the future, AI might be used to assist with real-time dose choices. Decisions on inventory management have become more common in clinical pharmacy practice as a result of the worldwide issue of medication shortages in recent years. A clinical chemist's time and energy may be significantly taken away from other critical responsibilities in providing safe, effective treatment while managing medication shortages and maintaining supply continuity. AI has the potential to improve the accuracy of medicine usage predictions in health-care systems and hospitals and to aid in clinical decision-making by identifying and evaluating alternative treatment options if a drug is unavailable [Figure 5].[35]

Adverse medical outcomes are more likely in elderly persons and younger at-risk groups who use many medications. By reviewing pharmaceuticals, clinical chemists may optimize their cost-effectiveness and clinical usage, which, when combined with patient preferences, should lead to better health outcomes. AI has the potential to revolutionize this field by providing new tools for the study of DDIs and their underlying processes, as well as for the prediction of safer pharmacological alternatives for clinical usage.[36] Pharmacovigilance aims to identify, track, characterize, and prevent hazardous medication reactions. The massive amounts of data acquired from post-marketing research, EMRs, and the Internet need the use of AI. Through the use of novel knowledge and expertise, clinical chemists may spearhead the integration of AI into pharmacovigilance.[37]

Furthermore, AI has the potential to improve the quality of medical care by reducing processing times and facilitating communication between patients and health-care providers. Digitalization has not eliminated the expensive bureaucratic burden that comes with many health-care operations. AI can also resolve the problem of scheduling conflicts or overbooking. To decrease readmissions, AI might prioritize appointment schedule according to readmission risk and total illness severity.[38]

Data analysis is made more appealing and practical using AI. Assessing the practicality of medication health-care results may include ongoing evaluation of current treatment choices for new diseases or authorized indications. This is helpful in medication repurposing as it allows an authorized new medicine to skip phase I clinical trials and toxicity testing and move straight to phase II studies for a different application.[39] There have been a lot of peer-reviewed articles on AI in the

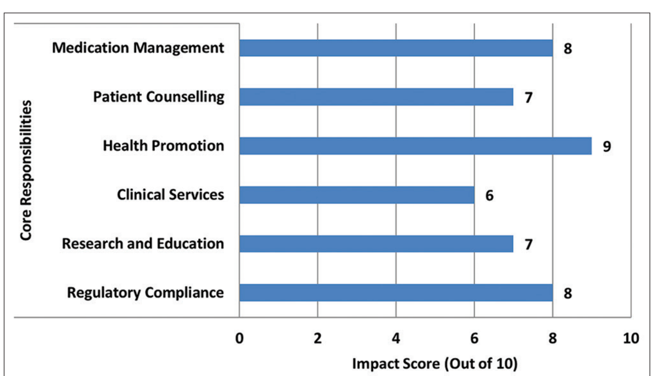

Figure 5: Impact on the core responsibilities of pharmacy practice

biological sciences, which is upstream from clinical practice yet has seen far quicker advancement. On many fronts, AI is reshaping the drug discovery process. AI is helping with biomedical literature searches, data mining of millions of molecular structures, molecule design and fabrication, off-target effect and toxicity prediction, experimental drug dose prediction, and large-scale cellular assay development.[40]

Health-care providers, chemists, and health systems have received more attention in the development of AI algorithms than patients and carers who want to take an active role in their healthcare. Health applications and wearables have the potential to go beyond just storing medical data and start actively advising patients on anything from diagnosis to medication modifications.[41] Using AI tools like chatbots for virtual coaching might potentially help manage common chronic ailments such as hypertension, depression, and asthma. Datasets used to train AI to improve health-care providers' capacity to care for patients must be inclusive of all demographics and free of sex, race, ethnicity, socioeconomic position, age, ability, and location biases. There is an ethical and data science concern with this demand for representation. Discrimination and injustice have taken place due to a lack of equitable representation.[42]

Despite research showing that AI can diagnose diseases just as well as human specialists, the majority of the relevant tools need evaluation in randomized controlled trials to determine how they impact health-care choices and patient outcomes.[43] Several major problems, such as inconsistent data quality and unclear guidelines on how to effectively incorporate AI into health-care processes, limit its potential use. The crucial but as-yet-unanswered issue is whether AI can, in the long run, enhance health-care quality while keeping costs down. Hence, it is crucial to exercise care while using AI technologies. Statistics and database research may often provide an ideal answer and can be simpler and cheaper to apply than AI solutions, thus it is not that AI is necessary for every problem.[44] It should confront the reality that AI is necessary, even if there are numerous obstacles to its use in pharmacy practice. It would be prudent to approach and hold solutions to problems such as new pharmaceutical policy initiatives, data protection, and cyber security regulation, the discussion of unusual accountability and responsibility issues, questions regarding the fiduciary relationship between patients and medical AI-based devices with the same ethical standards that have guided other players in the health-care system.[45]

SUSTAINABILITY, CHALLENGES, AND CASE STUDIES

AI in pharmacy requires some crucial approaches and procedures to ensure its long-term viability, efficacy, and moral integrity. Some of the approaches include ethical considerations and regulation (transparent algorithms; regulatory compliance;

and ethical guidelines), data management and security (robust data governance; data privacy; and continuous monitoring), environmental considerations (energy efficiency and green computing practices), continuous improvement and innovation (ongoing research and development and interdisciplinary collaboration), education and training (training health-care professionals and public awareness), economic and operational sustainability (cost-effective solutions and scalability) and user-centric design (patient-centered approach and feedback mechanisms). The sustainability of AI in pharmacy may be guaranteed by taking care of these issues, which will enhance patient outcomes, increase productivity, and benefit society and the environment.[46-48]

The integration of AI into the pharmacy sector has significant challenges, particularly regarding growing pharmaceutical policy initiatives, data protection, and cybersecurity regulations. The implementation of comprehensive and flexible regulatory frameworks is frequently required to effectively manage innovation, patient safety, and ethical concerns, following emerging regulations. Ensuring robust data privacy is crucial, as AI systems heavily rely on vast amounts of sensitive patient data. Complying with stringent regulations such as GDPR and HIPAA is essential to safeguard privacy and maintain trust. Furthermore, the increasing intricacy of cyber-attacks poses a continuous risk to AI systems, necessitating the adoption of sophisticated cybersecurity measures to prevent breaches and data manipulation. These issues necessitate collaboration between regulators, health-care providers, and tech developers to create AI solutions in pharmacies that are robust, secure, and compliant. Ensuring that these applications can withstand regulatory examination and effectively safeguard patient data are crucial.[49-51] There are many real-world case studies related to AI applications in pharmacy. However, it is not possible to explain all those studies to keep the length of the article to optimum. Interested readers can refer to the cited references for details.[52-55]

CONCLUSION

Pharmacists should think about the advantages of AI because of how common it is in pharmacy practice. According to this narrative evaluation, pharmacy automation boosts patient happiness by making treatment safer, and more efficient, and reducing human error. Hence, increasing the use of pharmacy automation in hospital pharmacies is of the utmost importance.

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ETHICAL STATEMENT

No ethical statement is required.

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