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ARTIFICIAL INTELLIGENCE (AI) IN PHARMACY

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ABSTRACT
Artificial Intelligence (AI) has revolutionized the pharmaceutical industry by allowing computer software systems to learn and mimic human behavior. In particular, AI has transformed the management of chronic diabetes through continuous glucose monitoring, highlighting its significant potential in the healthcare sector. Nevertheless, with its transformative effects, the growing presence of AI in healthcare has raised concerns regarding privacy and its hasty implementation. Despite these issues, AI presents endless possibilities for enhancing medication management and treatment plans, fostering progress in various fields. From improving CT imaging to boosting adenoma detection during colonoscopies and aiding medication adherence, the influence of AI on healthcare is substantial. Additionally, AI is crucial in patient education and safety, utilizing mobile application devices and predictive analysis systems to enhance outcomes. In situations involving polypharmacy, AI-driven computational techniques can identify possible drug-drug interactions. Consequently, for pharmacists, AI signifies a fundamental shift, enabling them to focus on patient-centered care in the face of modern healthcare challenges.
KEYWORDS: *General overview of AI, Adverse drug reactions, Drug-drug interactions, Patient education/safety, Role of pharmacist.*

INTRODUCTION
AI is revolutionizing the pharmacy sector by speeding up drug discovery and development, tailoring patient treatment plans, and enhancing operational efficiency through automation and data analysis. Key applications involve aiding clinical decision-making, including forecasting drug interactions and optimizing dosages, while also improving patient care by promoting adherence and managing medication. In general, artificial intelligence (AI) is employed to analyze machine learning in order to replicate the cognitive functions of humans. AI technology is utilized to conduct more precise analyses and to achieve valuable interpretations. From this viewpoint, various effective statistical models and computational intelligence are integrated into AI technology. Recently, AI technology has become an essential component of the industry, providing valuable applications across numerous technical and research domains. Looking back over the past 25 years, the pharmacy sector has effectively met the increasing demand for prescriptions, even amidst challenges such as pharmacist shortages, rising operational costs, and reduced reimbursements. Additionally, the pharmacy field has successfully harnessed enabling technology automation to enhance workflow efficiency and decrease operational expenses while ensuring safety, accuracy, and effectiveness in every pharmacy environment. Automated dispensing systems allow pharmacists to spend more time interacting with a larger number of patients, thereby improving health outcomes. The initial use of computers in pharmacies can be traced back to the 1980s, and since that time, computers have been applied in various areas including data collection, retail pharmacy management, clinical research, drug storage, pharmacy education, clinical pharmacy, and much more. With the advent of artificial intelligence, the potential for evolution within the pharmacy sector is limitless. Numerous expert systems have been created in the medical field to aid physicians in diagnosing illnesses. Recently, several programs concentrating on drug therapy have been introduced. These programs assist with drug interactions, monitoring drug therapy, and selecting drug formularies. There are numerous facets of pharmacy where AI can exert influence, and pharmacists should explore these opportunities as they may eventually become integral to pharmacy practice.

General Overview of AI
Artificial Intelligence (AI) has been integrated into the healthcare sector for a considerable period. AI refers to the capability of a computer software system to replicate human behavior. This field includes both machine learning (ML) and deep learning (DL). ML employs algorithms and statistical models to perform tasks autonomously.1 On the other hand, DL uses artificial neural networks to identify intricate patterns for making predictions.1 Both ML and DL facilitate personalized, evidence-based decision-making and problem-solving in patient care. As the pharmacy sector progresses, the workload for pharmacists is increasingly becoming burdensome due to vaccine administration, insurance claims, and a rise in prescription processing volume. Nevertheless, pharmacy is not the only domain that has undergone significant changes over the years. The healthcare industry has transformed dramatically through the adoption of electronic health records (EHR), automated medication dispensing systems (such as Omnicell and Pyxis), and continuous glucose

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monitoring devices (like FreeStyle Libre and Dexcom), among others. AI has demonstrated its ability to enhance clinical operations and workflows, minimize patient errors, and elevate the quality of personalized care, ultimately resulting in improved health outcomes.2 Pharmacists have leveraged AI to identify adverse drug reactions and drug-drug interactions, serving as a protective measure against potential patient harm. While AI holds immense promise in supporting healthcare professionals, it is not designed to replace trained staff.

Automated dispensing cabinets (ADCs) are secure medication storage units that dispense medications via computerized commands. Omnicell, a manufacturer of ADCs, has integrated AI technology to minimize medication errors by employing barcode recognition, which ensures accurate stocking and dispensing of medications. Furthermore, Omnicell, incorporates fingerprint access and inventory management systems, enhancing its capability to identify inventory trends and user behaviors to optimize stock levels and address any issues. Lastly, these ADCs can monitor drug expiration dates and alert the pharmacy when any medication in the bin is nearing its expiration date. Additionally, other systems leverage AI to support chronic diabetes management. The incidence of diabetes has steadily increased over the past ten years. According to the national diabetes statistics from the Centers for Disease Control and Prevention (CDC), 11.6% of the US population, equating to 38.4 million individuals, is affected by diabetes. AI has made significant progress in diabetes management through the development of continuous glucose monitoring (CGM) systems. A CGM consists of a biosensor with a small, flexible filament that is inserted under the skin. It continuously transmits real-time glucose levels from interstitial fluid to a device via Bluetooth, operating 24/7. This CGM system analyzes patient readings, identifies trends, and supplies data to assist healthcare providers and patients in managing diabetes effectively. The advancement of CGM technology is expected to result in a savings of $490 billion in healthcare costs. Figure 1 illustrates an example of the closed-loop control algorithm provided by the CGM for individuals with type 1 diabetes using an insulin pump. While the progress of AI has been advantageous, it may also pose potential drawbacks for the healthcare system, particularly in the pharmacy sector.

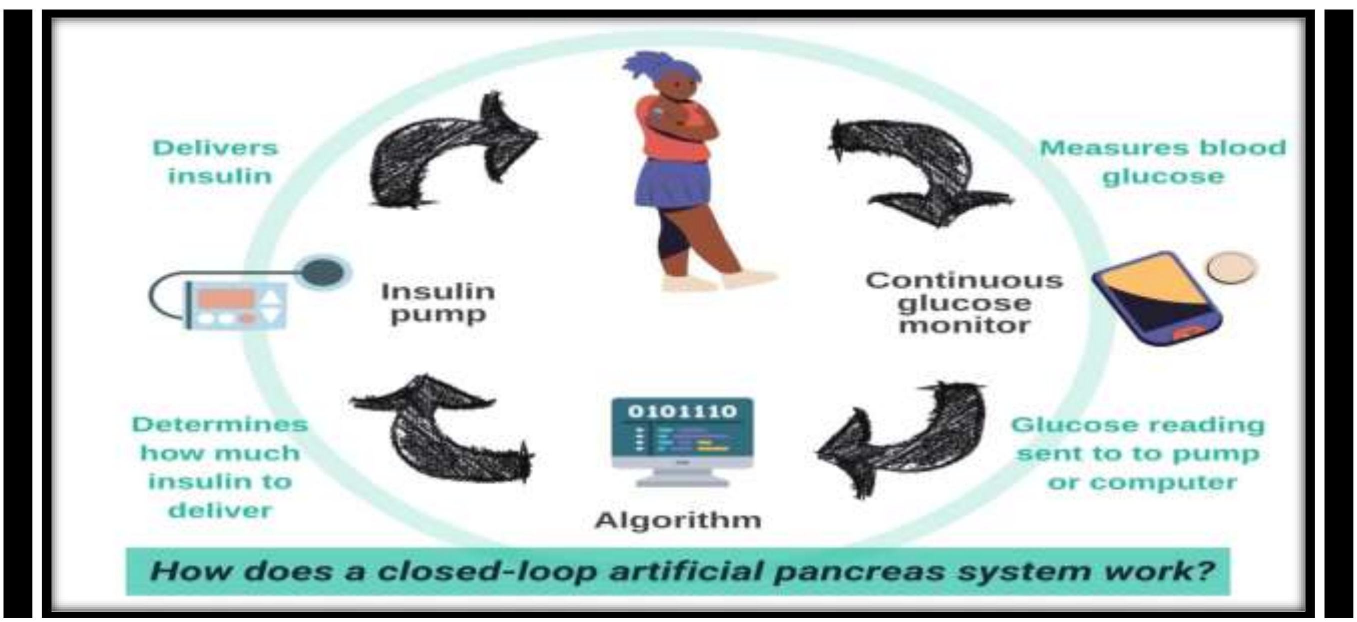

Figure 1: Continuous Glucose Monitor Closed Loop Feedback System

Negative views about AI

The growing involvement of AI in healthcare has sparked considerable public anxiety, particularly regarding privacy, which has become a critical concern. The merging of health data with technology has led to fears of network intrusions, data leaks, or the unauthorized sharing of protected health information. These apprehensions could materialize through deliberate and harmful hacking, technological failures that expose systems to breaches, or the illicit sale of patient data by or to companies involved in genetic testing and bioinformatics. Historically, pharmaceutical and biotechnology firms have been able to purchase customer data since these genetic testing companies are not subjected to stringent oversight. Given the novelty of this sector, legislative measures have struggled to keep up with the rapidly changing environment. Although regulations like the General Data Protection Regulation (GDPR) and the Genetic Information Nondiscrimination Act (GINA) provide some level of protection, there is still significant room for enhancement in safeguarding patient information. The application of AI technology in healthcare is still in its infancy, leading to worries about its hasty implementation. These concerns encompass privacy issues and technical difficulties, as previously mentioned, along with challenges in

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standardizing care. Perspectives differ on the potential for AI and medical robots to supplant human healthcare providers. Some contend that medical robots can deliver precision and efficiency in diagnosis and treatment, while others express legitimate concerns about the indispensable role of human empathy and compassion in the healing process. Indeed, medical robots are unable to convey these vital emotions, which are crucial for patient care and recovery.

Positive Influences of AI

Indication

Artificial Intelligence (AI) has demonstrated its influence on computed tomography (CT) by minimizing the required radiation dose. Manufacturers have developed deep learning (DL)-based reconstruction algorithms aimed at enhancing CT image smoothing and spatial resolution at specific dose levels. A clinical study was conducted to compare algorithms based on AI Reconstruction (AI-DLR) with earlier iterative reconstruction (IR) algorithms utilized in CT imaging. This study gathered 461 CT images from torso phantoms, which are objects designed to simulate a torso for quality control purposes, across five distinct dose levels. Radiologists evaluated the images for noise, smoothing, and overall quality. Image noise refers to the unwanted pixel values present in a cross-sectional image, while image smoothing eliminates clutter to produce a clearer image. This enhancement was found to facilitate the detection of lesions and lead to more accurate diagnoses. The findings of the study revealed that AI-DLR significantly reduced noise levels and enhanced the detectability of chest lesions at smoother settings. Consequently, this resulted in improved detectability and noise reduction in images that were free from pixelated clutter. Noise levels were reduced from -35.3% to -66.3% for mediastinal images, and CT images were averaged at smoother levels using AI-DLR.

AI is currently under evaluation to assess its effectiveness in detecting adenomas during a colonoscopy. Computer Aided Detection (CAD) AI systems have been tested to support endoscopists in identifying colorectal cancer during colonoscopy procedures. The CAD system detects colorectal polyps during white light colonoscopy examinations. It assists endoscopists by providing a visual cue when a polyp is recognized. A randomized clinical trial investigated the usefulness of CAD devices across five academic and community centers by board-certified gastroenterologists to evaluate the number of adenomas detected per colonoscopy using AI. Participants were recruited between January and September 2021. The study involved 1440 participants aged 40 and above who had a scheduled colonoscopy. Participants were randomly assigned to either CAD or standard endoscopies in a 1:1 ratio. Exclusion criteria included incomplete procedures, irritable bowel disease, and familial adenomatous polyposis. The primary endpoints were the number of adenomas per colonoscopy and the total count of resected adenomas per total number of colonoscopies. The findings of the study reveal that CAD devices (1.05) significantly enhanced ($p = 0.02$) the number of adenomas identified per colonoscopy in comparison to standard endoscopies (0.83).

Medication adherence is influenced by AI-generated "nudges," which modify a patient's behavior in a predictable manner without prohibiting alternative clinical choices. Nudging is implemented by incorporating medications into a patient's daily routine and integrating them into their everyday activities. These nudges are communicated through text messages, automated voice response calls, and emails. Personalized actions were sent to patients to enhance medication adherence. A randomized clinical trial examined the impact of behavioral nudging on adherence to statin therapy. 12 Participants were recruited from March 2016 to February 2018. This 12-month parallel study randomized 182 participants to receive a behavioral nudge or not. The primary objective of the study was to evaluate adherence to statin therapy 12 months post-baseline. Participants were deemed adherent if their proportion of days covered (PDC) exceeded 80%. The results indicated that AI-generated behavioral nudges (66.3%) significantly improved ($p = 0.036$) statin adherence compared to the placebo group without nudges (50.5%). Management of Acute Ischemic Stroke (AIS) is affected by the Clinical Decision Support System (CDSS) developed from AI. CDSS supports the evidence-based medicine approach utilized by neurologists in diagnosis and treatment. The StrokecoPilot project compiled 22 reference populations from two guidelines and 15 randomized clinical trials. This project is a neurologist-focused web application that employs CDSS to evaluate indications for intravenous thrombolysis and endovascular treatments. The aim of this project is to assist neurologists in managing the acute phase of AIS through a literature-based CDSS.

Patient Education/Safety

AI technology has significantly contributed to patient education and safety, especially through the creation of mobile applications. One notable example is the Bowel Preparation app, which was developed by the Institute of Gastroenterology and Hepatology in Vietnam. This mobile application aims to provide counseling for patients who are scheduled to undergo colonoscopy procedures. The app assesses patient eligibility and gathers medical history. It includes medical details such as medications, previous surgeries, and current allergies that may affect the colonoscopy process. To ensure patient privacy, all medical information is encrypted within the app. Additionally, the mobile app offers detailed instructions for bowel preparation and self-assessment. A randomized controlled trial indicated that counseling via the mobile app enhanced bowel preparation outcomes. Participants were divided into two groups: one with access to the

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mobile app and the other receiving standard care. Among 512 participants, 494 (96%) reported successful bowel preparation, as determined by the observation of water defecation (p = 0.05). Those in the intervention group demonstrated greater adherence to medication (60.9%) compared to the standard care group (52.4%).

Mobile AI-generated systems are currently being evaluated to assess their effectiveness in managing diabetes, primarily aimed at improving blood glucose control and enhancing self-management among patients with type two diabetes. The MHealth app tracks glucose levels, medication dosages, and identifies high-risk patients by analyzing dietary patterns and lab results logged by patients.22 This mobile application is presently undergoing testing to evaluate its effectiveness in diabetes management.

A randomized clinical trial was carried out across 45 community centers in Beijing, China.22 Participants were either given standard primary care or an electronic health education program that incorporated the mobile app. The main outcome of the trial was the change in HbA1C from baseline at one, three, six, twelve, and eighteen months. The trial is ongoing, and over an 18-month period, participants in the AI-assisted group will be monitored for blood glucose levels, medication adherence, quality of life, and HbA1C.

Current research is focusing on evaluating medication safety through AI. Drug safety is improved by AI systems that analyze extensive data and provide predictive analytics for future outcomes. The data analyzed includes randomized clinical trials, guidelines, evidence-based literature, and reports of adverse drug reactions. The United States Food and Drug Administration (FDA) has launched the Innovative Science and Technology Approach for New Drugs (ISTAND) program.23 This initiative creates a pathway for integrating new methods, such as AI, into drug development. AI is employed within this program to forecast outcomes, potentially replacing animal testing in drug development. It is crucial to understand that these AI-generated systems are designed to support pharmacists rather than replace them. They assist by enhancing the efficiency of pharmacists in ensuring drug safety.

Role of Pharmacist

AI is not replacing pharmacy; instead, it is enhancing the field. AI provides opportunities to elevate patient care, improve the drug supply chain, ensure safety, and manage medications effectively. This transition allows for a greater emphasis on patient-centered care by facilitating more personalized treatment. These innovations are relevant in both hospital and community pharmacy environments. IBM Watson is developing patient-specific cancer therapies by leveraging historical medical data, medical literature, and clinical trial information. Meanwhile, Google has introduced a machine that analyzes a patient's retinas to assess the risk of heart disease. Chemical Structure Representation (CASTER) is a tool designed to analyze drugs with similar structures to predict potential drug-drug interactions and adverse effects. Furthermore, AI can oversee inventory, forecast medication demand, and automate ordering processes to reduce stress and optimize the drug supply chain. This forecasting utilizes historical sales data, weather trends, local health statistics, and more. AI chatbots and virtual assistants have proven beneficial for patients by providing answers in easily understandable language. All these AI-driven advancements help reduce the administrative workload on pharmacy teams, enabling them to focus more on patient care.

Adverse Drug Reactions

AI has demonstrated advantages in sorting adverse drug reaction (ADR) data. In an era characterized by swift communication and widespread information sharing, patient reports often inundate pharmacovigilance (PV) systems, especially when health-related errors are highlighted in the media. This issue is not new; however, AI may offer an innovative solution. In 2008, the New Zealand Center for Adverse Reactions Monitoring faced a significant increase in ADR reports following a change in thyroxine formulation, which was widely covered by the media. A comparable situation occurred in France in 2017 with Levothyrox, resulting in a staggering 2000-fold rise in patient-reported ADRs. In both instances, PV reporting systems were overwhelmed by a rapid influx of reports, all necessitating manual sorting. This manual assessment of ADRs was labor-intensive, and AI has the potential to enhance efficiency. AI holds the promise of quickly identifying large volumes of ADRs found in the unstructured data from patient report forms. One study that examined the use of coding for patient-reported ADRs found that an AI pipeline could utilize a knowledge database to organize free-text data, as well as a machine learning model to learn ADR coding from human expertise, enabling the automatic identification of ADRs. This research also indicated that the most effective pipeline tested employed a light gradient boosting machine (LGBM), achieving impressive results, including an AUC of 0.93, which reflects a 93% accuracy in ADR identification, and an F-measure of 0.72, indicating a relatively strong predictive performance as the value approaches 1. Although the model successfully coded and identified 703 ADRs out of 1,061 in the test set, it did misidentify 190 cases. Nevertheless, the study concluded that this particular AI pipeline could accurately diagnose ADRs from patient reports when provided with unstructured data. While there is still room for improvement, it has significantly streamlined the coding of ADR reports, making it more efficient.

A separate study commissioned by the French Network of Pharmacovigilance Centers assessed advanced machine learning models intended for the automatic pre-coding of adverse drug reaction (ADR) reports submitted by patients.14 This research analyzed the

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performance of each AI model through a variety of metrics, calculated using 95% confidence intervals. The Term Frequency - Inverse Document Frequency (TF-IDF) combined with the LGBM model demonstrated significant outcomes, achieving an F-measure of 0.80 and an AUC of 0.97, which reflects impressive performance and accurate identification of 97% of ADRs. In a similar vein, the Cross-lingual Language Model (XLM) also produced commendable results, with an F-measure of 0.78 and an AUC of 0.97, indicating a high performance level with only a marginally lower score, while still identifying 97% of ADRs. External validation corroborated these results, with the TF-IDF + LGBM model achieving an F-measure of 0.82 and an AUC of 0.97, while the XLM model recorded an F-measure of 0.80 and an AUC of 0.97. The study effectively validated and trained two separate AI models to detect ADRs and evaluate their severity, all while adhering to the accuracy benchmarks established by the National Agency for the Safety of Medicines and Health Products (ANSM) for national development in France as of January 2021. This initiative was designed to support pharmacovigilance experts during the COVID-19 vaccination campaign, anticipating a significant rise in reported ADRs. The research highlighted the necessity for ongoing studies and enhancements to ensure the reliability of the AI models' performances in practical scenarios, as well as to identify the most effective models for further performance improvement.14 In summary, AI holds great potential for both present and future uses in identifying and evaluating ADRs, while also helping to reduce the workload of pharmacovigilance teams.

Drug-Drug Interactions

It is crucial to remain vigilant about the potential risks that may emerge in today's polypharmacy landscape. Polypharmacy carries the risk of drug-drug interactions, which can lead to adverse drug reactions (ADRs), and artificial intelligence (AI) might be capable of predicting or identifying these interactions. The computational techniques currently utilized to identify drug-drug interactions include machine learning (ML), similarity-based methods, and network-based approaches, all of which have proven effective in forecasting drug-drug interactions. ML functions by integrating diverse data and amalgamating information related to adverse reactions, signaling pathways, target similarities, and protein-protein interaction networks. Similarity-based methods analyze comparable drug profiles to evaluate gene expression and phenome profiles, determining whether a specific drug combination may lead to structural or functional incompatibility. Network-based methods focus on the interactions among multiple drug mechanisms, offering greater effectiveness due to their capacity to interpret mechanistic actions without depending on the structure of each drug to predict the presence of a reaction. Additionally, there are large-scale predictors of drug-drug interactions that identify five categories of drug similarities: 2D molecular structure similarity, 3D pharmacophoric similarity, drug interaction profile similarity, target similarity, and adverse effect similarity. Currently, association rule mining is being used to identify drug-drug interactions.

It is essential to closely monitor potential risks that may emerge in today's polypharmacy landscape. Polypharmacy carries the risk of drug-drug interactions, which can lead to adverse drug reactions (ADRs), and artificial intelligence (AI) might be capable of predicting or identifying these interactions. The computational techniques currently utilized to identify drug-drug interactions include machine learning (ML), similarity-based methods, and network-based approaches, all of which have proven effective in forecasting drug-drug interactions. ML operates by integrating diverse data and amalgamating information related to adverse reactions, signaling pathways, target similarities, and protein-protein interaction networks. Similarity-based methods analyze comparable drug profiles to evaluate gene expression and phenome profiles, determining whether a specific drug combination may cause structural or functional incompatibility. Network-based methods focus on the interactions among multiple drug mechanisms, offering greater effectiveness due to their capacity to interpret mechanistic actions without depending on the structure of each drug to predict potential reactions. Additionally, there are large-scale predictors of drug-drug interactions that identify five categories of drug similarities: 2D molecular structure similarity, 3D pharmacophoric similarity, drug interaction profile similarity, target similarity, and adverse effect similarity. Currently, association rule mining is utilized to identify drug-drug interactions.

CONCLUSION

AI has the potential to revolutionize the healthcare sector for providers and clinicians. From advancements in CT imaging and enhanced diagnostic accuracy to streamlined ADR reporting and better patient adherence, AI presents healthcare advocates with numerous opportunities to improve patient outcomes. For example, mobile AI-driven systems like the Bowel Preparation app have demonstrated their ability to boost patient compliance with medical directives, leading to improved readiness for procedures such as colonoscopies. These innovations also benefit the healthcare system overall by alleviating the burden on medical staff and lowering costs related to medical errors and missed diagnoses. Patients will experience advantages beyond the hospital setting through mobile applications that assist them in remembering their medications or facilitate easier communication of information back to their healthcare teams. Although privacy concerns remain, ongoing regulatory initiatives aim to tackle these challenges. The incorporation of AI into pharmacy practice has enabled pharmacists to provide more tailored treatments and focus on patient care.

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