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A REVIEW ARTICLE ON INNOVATIVE ARTIFICIAL INTELLIGENCE IN PHARMACY

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ABSTRACT

With its creative solutions to enhance drug development, clinical trials, customized treatment, and pharmacy operations, artificial intelligence (AI) is rapidly changing the pharmaceutical sector. AI technologies such as machine learning (ML), natural language processing (NLP), and data analytics enable the analysis of vast datasets, accelerating the identification of potential drug candidates, optimizing treatment regimens, and enhancing patient outcomes. In drug development, AI models can predict the efficacy and safety of compounds, reduce the time and cost of clinical trials, and facilitate precision medicine by tailoring therapies to individual genetic profiles. In pharmacy practice, AI-powered systems can support medication management, identify drug interactions, and assist in clinical decision-making. Furthermore, AI-driven automation and robotics are streamlining pharmacy workflows, improving accuracy, and reducing human errors. While the potential of AI in pharmacy is vast, challenges such as data privacy, algorithm transparency, and regulatory approval must be addressed for its widespread adoption. This abstract highlights the key roles AI plays in modern pharmacy and its future implications for improving healthcare delivery.

KEYWORDS: Artificial Intelligence in Pharmacy, Artificial Intelligence in Drug Discovery and Development, AI in Personalized Medicine, AI in Adverse Drug Reaction, AI in Pharmacy Operations, AI in Healthcare.

1. INTRODUCTION

Pharmacy is just one of the industries that artificial intelligence (AI) is transforming. In recent years, AI has demonstrated its potential to transform how drugs are discovered, developed, and dispensed, offering significant improvements in accuracy, efficiency, and patient care. AI technologies, including machine learning, natural language processing, and data analytics, are increasingly being integrated into pharmacy practices, from drug discovery to personalized medicine.

In the drug discovery process, AI can predict how different compounds might behave in the human body, thus accelerating the development of new treatments. AI systems analyze vast datasets, such as genomic information, medical literature, and clinical trials, to uncover insights that would be impossible for humans to detect manually. In addition, AI-driven algorithms are being used in pharmacy settings for inventory management, optimizing supply chains, and even enhancing patient safety by identifying potential drug interactions or adverse effects.[1]

Personalized medicine, an emerging trend in healthcare, also benefits from AI's capabilities. AI can analyze individual patient data to tailor medication regimens based on genetic, environmental, and lifestyle factors, ensuring more effective and safer treatments. Furthermore, AI in pharmacy assists in automating routine tasks like prescription verification and dispensing, allowing pharmacists to focus more on patient counseling and clinical care.

Overall, AI's potential in pharmacy is vast, offering improvements in drug development, personalized treatment, and operational efficiencies, all of which contribute to better patient outcomes.[2]

1.1 Ai in drug Discovery and Development

Artificial intelligence (AI) is revolutionizing the pharmaceutical industry by significantly enhancing the process of drug discovery and development. AI techniques, particularly machine learning (ML), deep learning, and natural language processing (NLP), are being increasingly applied to various stages of drug development. These technologies help in identifying potential drug candidates, optimizing clinical trial designs, predicting drug interactions, and personalizing treatment plans.

1. Drug target Identification and Validation

AI can analyze vast amounts of biological data to identify novel drug targets (proteins or genes) that are implicated in diseases. Traditional methods for target identification are time-consuming and costly, whereas AI accelerates this process by mining biological data from multiple sources, such as genomic, proteomic, and transcriptomic databases. Machine learning algorithms can detect patterns in these complex datasets to predict which targets are most likely to be effective.

Example: A study published in Nature Biotechnology demonstrated that AI models were able to predict potential therapeutic targets in cancer cells by analyzing large-scale genomic data (Joulin et al., 2017).[3]

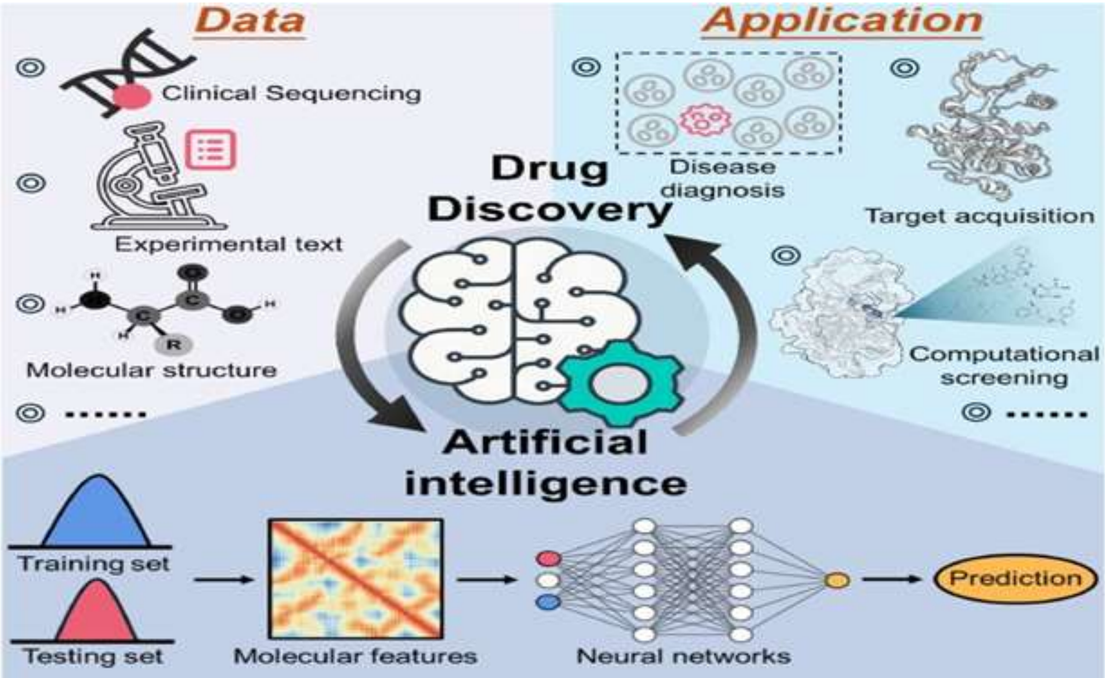

Fig. 1:- Artificial intelligence in drug Discovery and Development.[47]

2. Drug screening and lead compound identification

AI algorithms can assist in high-throughput screening (HTS) of chemical compounds to identify promising drug candidates. By training machine learning models on existing databases of molecular properties and known biological activities, AI can predict the likelihood that a compound will exhibit a desired biological effect. This approach is much faster and cost-effective compared to traditional HTS methods.

Example: Atomwise, a company using AI for drug discovery, applied deep learning to identify potential inhibitors for the Ebola virus and other diseases. Their AI platform analyzes the molecular structure of compounds and predicts how well they may bind to specific targets.[4]

3. Predicting drug-drug interactions (DDIS)

AI models can predict potential drug-drug interactions (DDIs) by analyzing chemical, biological, and clinical data. DDIs are a significant concern in drug development as they can lead to adverse effects or reduced efficacy. AI tools can Lessen the possibility of safety problems in clinical trials by assisting with the early detection of possible interactions during the medication development process.

Example: IBM Watson for Drug Discovery has been used to predict and identify DDIs by analyzing scientific literature and databases, offering insights into how different drugs may interact in a patient's body.

4. Optimizing clinical trials

AI has a transformative role in clinical trial design and management. Machine learning can be applied to optimize patient recruitment by identifying suitable candidates based on genetic, demographic, and clinical data. AI can also be used for monitoring patient responses in real time, enhancing trial efficiency, and reducing the time it takes to bring a drug to market.

Example: DeepMind, a subsidiary of Alphabet (Google), used AI to optimize the design of clinical trials for Alzheimer's disease. Their AI system helped in identifying patient cohorts that were more likely to respond to certain treatments.[5]

5. Biomarker discovery

AI can be used to identify biomarkers that can be used for disease diagnosis, prognosis, and treatment response monitoring. By analyzing complex datasets, including genetic, epigenetic, and proteomic data, AI systems can uncover new biomarkers that are predictive of treatment outcomes.

Example: A study published in The Lancet Oncology demonstrated how AI was used to identify predictive biomarkers for non-small-cell lung cancer, which could help in selecting patients for immunotherapy (Chen et al., 2020).[6]

6. Drug repurposing

AI has shown promise in identifying new uses for existing drugs, a process known as drug repurposing. By analyzing existing drug databases and medical literature, AI can predict which approved drugs might be effective against other diseases, reducing the time and cost associated with developing new treatments.

Example: BenevolentAI, an AI company, used machine learning to analyze existing drug data and discovered a potential treatment for COVID-19, identifying Baricitinib, a drug used for rheumatoid arthritis, for the treatment of the disease.[7]

1.2 Key ai techniques in drug discovery

1. Machine learning (ml) for drug target prediction

Machine learning models are used to predict potential drug targets by analyzing large datasets of biological information, such as protein sequences, gene expression data, and molecular interactions.[8]

2. Deep learning for drug-drug interaction (ddi) prediction

Deep learning models, particularly convolutional neural networks (CNNs) and recurrent neural networks (RNNs), are used to predict potential drug-drug interactions (DDIs) by analyzing chemical structures, side effects, and other drug-related data.[9]

3. Generative models for drug design (e.g., gans)

Generative adversarial networks (GANs) and other generative models are used to design novel molecules with specific desired properties (e.g., high binding affinity to a target protein).

Example: GANs can be trained to generate novel drug-like molecules based on the distribution of known active compounds.[10]

4. Virtual screening with ai models

Virtual screening techniques use machine learning models to quickly predict the binding affinity of compounds to biological targets, effectively narrowing down large chemical libraries to a smaller set of potential candidates for experimental testing.[11]

5. Reinforcement learning for drug optimization

Reinforcement learning (RL) is used to optimize drug properties iteratively, such as improving binding affinity, solubility, or other pharmacokinetic properties.[12]

6. Literature mining with natural language processing (nlp)

NLP techniques are used to mine scientific literature and extract valuable insights, such as drug interactions, side effects, and biomarkers. NLP models can process large amounts of unstructured data from research papers, clinical trial reports, and patents.[13]

7. Omics data integration

Integrating multi-omics data (Genomics, transcriptomics, proteomics, etc.) using AI techniques helps identify biomarkers, drug targets, and therapeutic strategies. This approach utilizes techniques like multi-instance learning or ensemble learning for better predictive accuracy.[14]

1.3 Ai application in drug discovery include

1. Target Identification and Validation

AI can analyze vast amounts of biological data, such as genomics, proteomics, and transcriptomics, to identify potential drug targets. AI algorithms can predict the involvement of specific genes or proteins in diseases and evaluate their druggability.

Example: DeepMind's AlphaFold has made strides in predicting protein structures, which aids in identifying new drug targets. The ability to predict protein folding accurately is critical for understanding diseases at the molecular level and designing drugs that interact with these proteins.[15]

2. Drug Discovery and Design

AI-powered algorithms are used to predict the chemical properties and biological activity of molecules, accelerating the identification of promising drug candidates. Virtual screening and generative models can be employed to design novel molecules with desired properties.

Example: AI tools such as Atomwise's deep learning model help predict how small molecules will interact with biological targets, significantly reducing the need for time-consuming and expensive experimental testing.[16]

3. Drug repurposing

AI can also facilitate drug repurposing, which involves finding new uses for existing drugs. By analyzing data from clinical trials, medical records, and scientific literature, AI can predict which approved drugs may be effective for other diseases.

Example: BenevolentAI used AI to identify Baricitinib, an existing drug for rheumatoid arthritis, as a potential treatment for COVID-19.[17]

4. Preclinical and Clinical trials optimization

AI can streamline clinical trial design by analyzing large datasets from previous trials to identify the most relevant patient populations, optimize dosing regimens, and predict adverse reactions. This helps reduce the risk of trial failure and accelerates the development process.

Example: IBM Watson for Drug Discovery uses AI to mine scientific literature and clinical trial data, helping researchers identify potential clinical trial candidates and biomarkers for disease.[18]

5. Toxicology prediction

AI can help predict the toxicity of new compounds before they enter clinical trials, minimizing the risk of failure and ensuring safety. Based on past data, AI algorithms are able to evaluate chemical structures and forecast possible toxicity.

Example: The use of AI by companies like Cyclica and Benevolent AI in predicting off-target effects and toxicity profiles of small molecules has gained significant attention.[19]

6. Personalized medicine

AI is enabling more personalized approaches to drug discovery, particularly in oncology and rare genetic diseases. By integrating patient-specific data (genomic, proteomic, etc.), AI can predict which treatments will be most effective for individual patients.

Example: Tempus is an AI-driven company that uses real-world clinical and molecular data to help personalize cancer treatments, improving outcomes by selecting the right drugs for the right patients.[20]

7. Synthetic Biology and Ai in drug manufacturing

AI can aid in designing synthetic biological systems for drug production. This includes optimizing metabolic pathways and identifying the most efficient microbial strains for producing biologics or small molecules.

Example: AI-driven platforms like those developed by Ginkgo Bioworks are used to optimize the production of therapeutic proteins and other biologic drugs.[21]

1. Challenges and Limitations in ai-driven drug discovery

Despite the transformative potential of AI in drug discovery, several challenges need to be addressed for it to achieve its full potential:

- **Data Quality and Availability:** AI models require high-quality, large-scale datasets for effective training. However, much of the data in drug discovery is fragmented, incomplete, or proprietary, which can limit the effectiveness of AI models. Ensuring access to standardized, high-quality datasets is crucial for reliable AI-driven drug discovery.[22]

- **Interpretability of ai models:** Many AI models, particularly those based on deep learning, operate as "black boxes." This means that even though they make accurate predictions, it can be difficult for researchers to understand how these predictions were generated. This lack of interpretability poses a challenge in regulated fields like drug discovery, where transparency and explainability are necessary for validating and adopting new drugs.[23]

2. Ai in personalized medicine

Personalized medicine, also known as precision medicine, aims to tailor medical treatment to individual patients based on their unique genetic makeup, environment, and lifestyle. AI plays an essential role in enabling this approach by analyzing each patient's data to provide highly customized care.

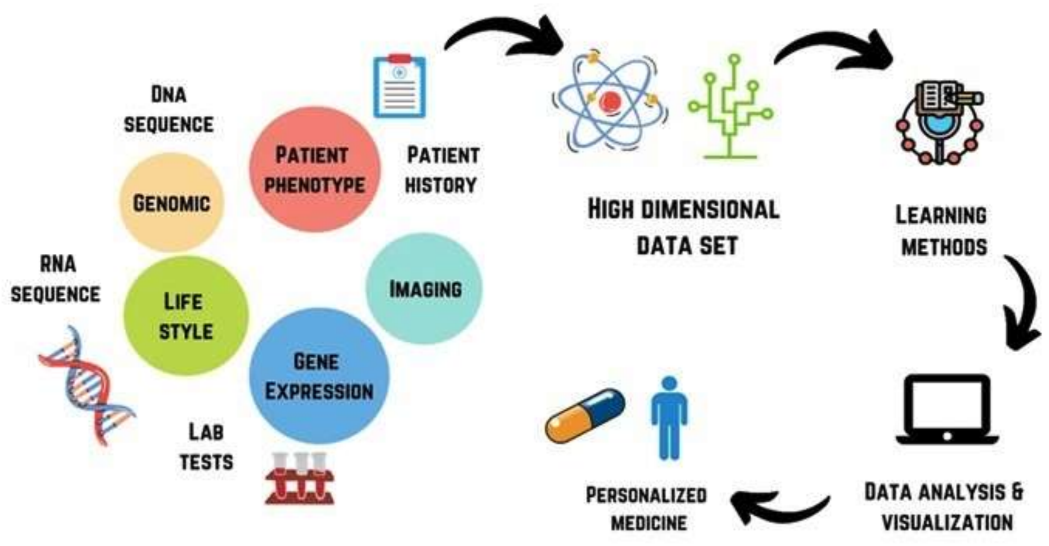

Fig. 2:- AI in Personalized Medicine.[48]

2.1 Understanding Genes and DNA

AI is instrumental in analyzing genetic information, a foundational aspect of personalized medicine. Each individual has a unique genetic profile, and AI can interpret this data to:

1. Genetic Testing and Disease risk

Genetic testing entails examining an individual's DNA to find alterations (variations or mutations) that could raise their chance of contracting specific illnesses. The risk is increased for people who have one copy of this allele and significantly higher for those who have two copies.

Hereditary cancer syndromes: Mutations in genes like BRCA1 and BRCA2 significantly increase the risk of breast and ovarian cancer in women, and prostate cancer in men. Individuals with these mutations may have a 50-80% chance of developing these cancers.

Cardiovascular diseases: Variants in genes such as LDLR (which encodes the LDL receptor) can cause familial hypercholesterolemia, leading to early-onset cardiovascular diseases due to high cholesterol levels.

Neurodegenerative diseases: The APOE gene, particularly the APOE4 allele, is associated with an increased risk of Alzheimer's disease. The risk is increased for people who have one copy of this allele and significantly higher for those who have two copies.

Cystic fibrosis: Caused by mutations in the CFTR gene, this disease affects the respiratory and digestive systems, with individuals inheriting two defective copies of the gene.(24)

2. Polygenic risk scores (PRS)

For complex diseases like diabetes, heart disease, and certain cancers, researchers have developed polygenic risk scores (PRS) that aggregate the effects of multiple genetic variants. However, lifestyle and environmental factors still play a significant role in the actual development of these diseases.

Type 2 diabetes: Genetic variants in genes like TCF7L2 and KCNJ11 can increase susceptibility to type 2 diabetes.

Heart disease: Genetic variants in the 9p21 locus, among others, have been associated with coronary artery disease.[25]

3. Rare genetic disorders

In some cases, single-gene mutations can lead to rare but severe diseases. For example:

Sickle cell disease: Caused by a mutation in the HBB gene, sickle cell disease results in abnormal hemoglobin, leading to severe anemia and related complications.

Huntington's disease: Caused by a mutation in the HTT gene, this neurodegenerative disorder leads to progressive motor dysfunction and cognitive decline, typically developing in mid-adulthood.[26]

4. Gene-environment interactions

Genetic predispositions interact with environmental factors (such as diet, exercise, or exposure to toxins) to influence disease risk. For instance:

Smoking is a strong environmental risk factor for lung cancer, but certain genetic variants (such as in the CHRNA5 gene) may increase susceptibility in smokers.

Diets high in saturated fats, combined with genetic variations in lipid metabolism genes (such as APOE), can further elevate the risk of cardiovascular disease.[27]

5. Ethnic and Population differences

Genetic disease risk can vary across populations due to differences in allele frequencies. For example:

Thalassemia: More common in individuals of Mediterranean, African, and Southeast Asian descent, it is caused by mutations in the HBB gene.

Tay-Sachs disease: A genetic disorder more prevalent in Ashkenazi Jewish populations, caused by mutations in the HEXA gene.[28]

2.2. Choosing the right medications (Pharmacogenomics)

One important area of AI's application in personalized medicine is pharmacogenomics, which studies how a person's genes impact how they react to medications. People often react differently to medications based on their genetics, and AI assists clinicians in determining:

- **Optimal drug selection:** AI can analyse genetic information to predict which drugs will be most effective for each patient, reducing the trial-and-error period of finding the right treatment.

- **Dosage customization:** AI can recommend personalized doses for patients, minimizing the risk of adverse reactions and improving drug efficacy. For example, two patients taking the same medication may require different dosages based on their genetic profiles, ensuring that each gets the best possible results.

Examples of pharmacogenomic applications

Warfarin: Warfarin is an anticoagulant whose dose can vary widely from patient to patient. Genetic testing for polymorphisms in the VKORC1 and CYP2C9 genes helps predict the optimal dose, reducing the risk of bleeding or clotting complications.[29]

CYP450 Enzymes and Antidepressants: Variations in CYP2D6 and CYP2C19 affect how patients metabolize common antidepressants like fluoxetine, paroxetine, or venlafaxine. Knowing a patient's genotype can help avoid adverse effects or lack of therapeutic response.[30]

HER2 and Trastuzumab: Testing for HER2 gene amplification in breast cancer has led to the targeted use of trastuzumab, improving outcomes for patients with HER2-positive tumors.[31]

Carbamazepine and HLA-B 1502: Genetic testing for the HLA-B1502 allele, common in certain Asian populations, helps predict the risk of severe skin reactions (e.g., Stevens-Johnson Syndrome) in response to carbamazepine.[32]

2.3 Creating new treatments

AI enables the development of new drugs tailored to patients with specific genetic profiles, offering a way to treat diseases with a more individualized approach.

- **Examples:** AI can help develop treatments for rare diseases that affect small groups of patients with particular genetic mutations. By focusing on these unique needs, AI assists in creating targeted therapies that address the underlying causes of disease in specific populations.

2.4 Predicting disease risks

AI models assess a combination of genetic, environmental, and lifestyle factors to predict a person's risk for various diseases. Preventative care that is customized to a person's health profile is made possible by this predictive capacity.

- **Examples:** AI might determine that someone has a higher risk for heart disease based on their genetic data and lifestyle, allowing healthcare providers to recommend preventive steps such as dietary changes or increased monitoring to lower that risk.

2.5 Challenges in ai-powerd personalized medicine

Despite its potential, personalized medicine faces certain challenges, including:

- **Data privacy:** Protecting sensitive genetic and health data is paramount, as breaches can have serious implications for patients. Data privacy measures are crucial to secure patients' personal health information in AI-powered healthcare.

- **Cost and Access:** Access to advanced AI tools in healthcare is not universal, especially in low-income areas. Ensuring equitable access to personalized medicine is essential to prevent healthcare disparities.

Here's an in-depth addition to the review paper covering Adverse Drug Reactions (ADR) and Pharmacy Operations, with a focus on how Artificial Intelligence (AI) is used to advance both areas:

3. Artificial intelligence in adverse drug reactions (ADR)

Adverse Drug Reactions (ADRs) are a significant concern in healthcare, often resulting in patient harm, increased healthcare costs, and delays in treatment. Traditional methods for ADR detection involve post-marketing surveillance, spontaneous reporting systems (SRS), and clinical trials. However, these methods have limitations, such as underreporting and delayed identification of rare ADRs. Artificial Intelligence (AI) has emerged as a powerful tool to enhance ADR detection, prediction, and management by analyzing vast amounts of healthcare data efficiently and accurately.

1. AI for ADR Prediction and Detection

AI can analyze electronic health records (EHRs), patient demographics, medical histories, and genetic information to predict ADRs. Machine learning algorithms, such as supervised learning, deep learning, and natural language processing (NLP), are particularly useful for identifying ADRs early, even from unstructured data like clinical notes.

Machine learning models: These models can be trained on historical data to predict ADRs based on patterns found in patient records. Studies have shown that machine learning algorithms, such as support vector machines (SVMs), random forests, and neural networks, can improve ADR prediction accuracy.

Natural Language Processing (NLP): NLP techniques can process unstructured clinical text to extract relevant ADR information, which is crucial since ADRs are often described in free-text reports or clinical notes. A study by Zhang et al. (2020) demonstrated the application of NLP for extracting ADR information from electronic health records, significantly improving the detection rate compared to traditional methods (Zhang et al., 2020).

Pharmacovigilance databases: AI has been applied to mining pharmacovigilance databases like the FDA Adverse Event Reporting System (FAERS) and the WHO's VigiBase to identify and analyze ADR patterns. AI models have been shown to outperform traditional signal detection methods by uncovering hidden relationships between drugs and ADRs.(33)

2. AI in Drug Repurposing to Prevent ADRs

AI also plays a role in identifying potential drug repurposing opportunities by predicting off-target effects that could lead to ADRs. By simulating drug-receptor interactions and analyzing chemical structure similarities, AI can help predict which drugs might cause unexpected reactions, enabling earlier identification of safety concerns.

Deep Learning and Drug repurposing: A study by Zhou et al. (2020) used deep learning techniques to identify potential ADRs associated with existing drugs, thereby allowing the prediction of drug-repurposing opportunities (Zhou et al., 2020). This can help clinicians find safer alternatives and mitigate ADR risks.[34]

3. AI for Real-Time ADR Monitoring

AI can be integrated into real-time clinical decision support systems (CDSS) to monitor ADRs as they occur. These systems can alert healthcare providers when an ADR is detected based on real-time data from EHRs and other sources.

Real-Time surveillance systems: AI-powered systems, such as those using predictive analytics and real-time data mining, can alert clinicians about potential ADRs during patient care, leading to faster intervention and minimizing harm. These systems are capable of processing large amounts of real-time patient data, improving detection speed and accuracy.[35]

4. Artificial intelligence in pharmacy operations

The application of AI in pharmacy operations optimizes workflows, improves patient care, and enhances overall efficiency in healthcare delivery. From automating prescription fulfilment to optimizing inventory management, AI is transforming how pharmacies function, making them more efficient, accurate, and responsive to patient needs.

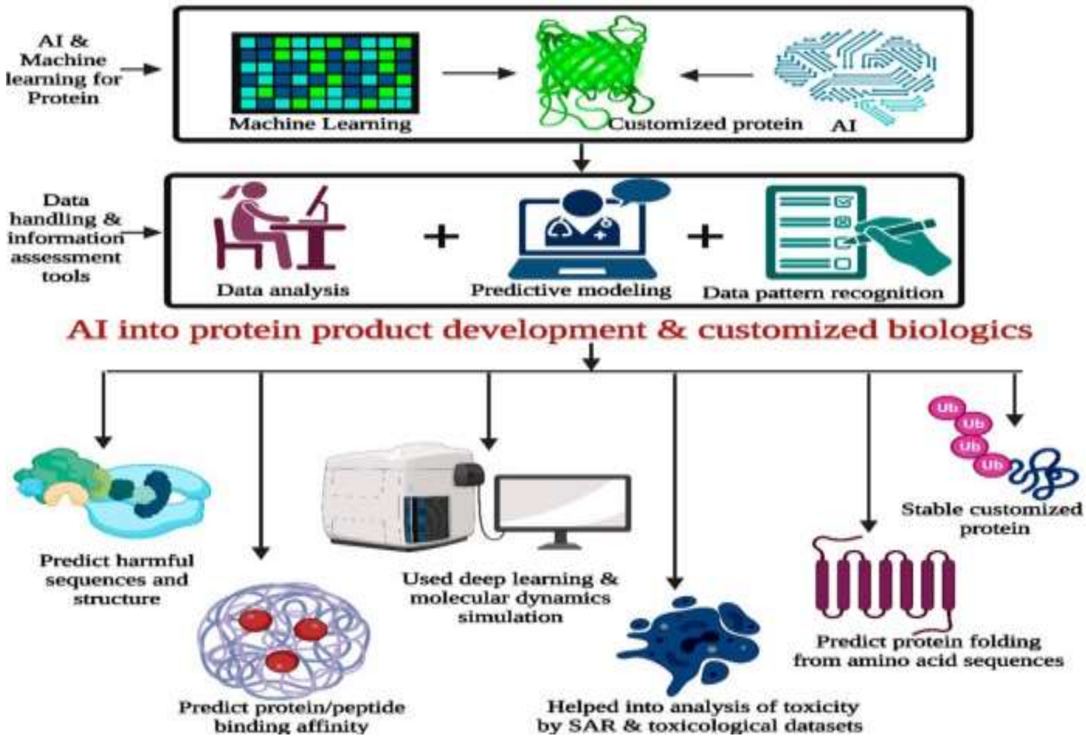

Fig. 3: Artificial intelligence in pharmacy operations.[49]

4.1 Automated prescription processing and dispensing

AI-powered automation is streamlining the prescription process, improving accuracy and speed while reducing human error.

- **Automated prescription processing**

Prescription Verification and Validation: AI-powered systems can cross-check prescriptions against patient records, identifying potential drug interactions, allergies, and discrepancies in dosage. Natural language processing (NLP) algorithms are also used to interpret handwritten or digitally scanned prescriptions, reducing the risk of errors.[36]

Error Detection and Prevention: AI tools can automatically flag common errors such as incorrect medication, wrong dosage, or mismatched patient information. For example, deep learning models can analyze the prescription text and patient history to identify any potential issues before the medication is dispensed.[37]

- **Automated dispensing system**

Patient Safety and Compliance Monitoring: AI can help ensure that patients receive the right medication at the right time. AI can track prescription fulfillment and alert pharmacists or patients if there are missed doses or incorrect administration times.[38]

Inventory management: AI-driven inventory management systems help pharmacies track medications' stock levels, expiration dates, and reorder points. These systems can predict demand based on trends and seasonal factors, ensuring that pharmacies are always prepared without overstocking.[39]

4.2 Inventory Management and Optimization

AI-driven inventory management systems help pharmacies manage stock levels, track demand, and reduce waste, ensuring that essential medications are always available.

- **Demand forecasting:** Machine learning algorithms predict demand for different medications by analyzing historical sales data, seasonal trends, and even external factors like health alerts or local epidemiological data. By predicting demand, pharmacies can ensure they have sufficient stock on hand while minimizing overstock, reducing both waste and cost.

- AI-integrated inventory systems that automatically create purchase orders based on current stock levels and anticipated demand are known as automated reordering systems. These systems help pharmacies avoid stockouts and ensure that critical medications are available when needed, ultimately supporting better patient care and preventing disruptions.

4.3 Benefits of ai in prescription Processing and Dispensing

- **Increased accuracy:** AI can reduce human error, which is crucial in pharmacy operations, particularly in prescription interpretation and dispensing.

- **Enhanced efficiency:** AI can speed up prescription processing and dispensing, allowing pharmacists to focus on patient care rather than administrative tasks.

- **Improved patient safety:** AI's ability to flag drug interactions, allergies, and incorrect dosages can prevent adverse drug events.

- **Cost savings:** Automation reduces labor costs and the resources required to manage prescription processing and dispensing.

- **Improving patient compliance:** AI-powered mobile applications and reminders help patients adhere to their medication regimens. These apps offer features like personalized reminders, medication tracking, and educational resources to enhance understanding and adherence. AI can also use predictive modelling to identify patients who may struggle with compliance and offer tailored support to improve adherence rates.[36,37,38,39]

4.4 Optimizing patient Engagement and Support

AI enables pharmacies to play a more active role in patient engagement by offering personalized support and information.

- **Engaging patients in shared decision-**

Making processes leads to better understanding and ownership of treatment decisions. Patients are more likely to adhere to treatment programs when they believe they have a say in the decisions made.[40]

- **Improved Access to Care and Support**

Ensuring that patients have easy access to care, whether through in-person visits or remote consultations, plays a significant role in improving engagement. Additionally, providing continuous support through nurse helplines, case managers, or peer support groups can encourage patients to stay engaged in their care.[41]

4.5 Streamlining clinical decision support in pharmacies

AI enhances clinical decision support in pharmacies, enabling pharmacists to make better-informed decisions about patient care and treatment options.

- **Advanced Clinical Decision Support Systems (CDSS)**

AI-powered CDSS tools provide pharmacists with real-time insights and recommendations on medication management, safety precautions, and alternative therapies. These systems are particularly useful for complex cases, as they integrate data from EHRs, drug databases, and clinical guidelines, allowing pharmacists to offer more precise advice and support for patient care.

- **Integration with Electronic Health Records (EHRs)**

Integration between pharmacy systems and EHRs enhances the accuracy and timeliness of information. Pharmacists have immediate access to patient health data, including lab results, medication history, and allergies, enabling more accurate decision-making at the point of care.[42]

- **Medication Therapy Management (MTM) Automation**

Automating certain aspects of MTM (e.g., identifying patients at risk for adverse drug events, reviewing medication regimens) can increase the efficiency of pharmacy operations. CDS tools embedded in pharmacy systems can automatically flag high-risk patients or drug interactions, which pharmacists can then review and act upon.[43]

AI Application	Description	Potential impact
Clinical Decision Support Systems (CDSS)	AI-driven CDSS tools provide pharmacists with real-time insights for medication management and safety precautions.	Enhances patient care quality, supports accurate medication recommendations, and reduces adverse drug outcomes.
Post-Market Surveillance	Uses NLP and data mining on EHRs, social media, and pharmacovigilance databases for real-time ADR monitoring.	Speeds up ADR detection post-market, supporting timely regulatory responses and improved patient safety.
Inventory Management	AI-based demand forecasting and automated reordering ensure optimal stock levels and minimize waste.	Reduces stockouts and excess inventory, lowering operational costs and ensuring essential drugs are always available.
Drug-Drug Interaction Checks	Analyses patient data and drug interactions to prevent harmful drug combinations.	Reduces adverse events, increases patient safety, and optimizes prescription accuracy.
Robotic Dispensing Systems	AI-guided robotics automate prescription filling, improving speed and accuracy.	Lowers dispensing errors, frees up pharmacists for patien interactions, and enhances operational efficiency.

CONCLUSION

Artificial Intelligence (AI) has revolutionized the field of pharmacy by enhancing drug discovery, improving patient care, and optimizing operational efficiency. AI-driven tools, including machine learning (ML), natural language processing (NLP), and predictive analytics, have significantly impacted various aspects of pharmacy practice, including medication management, personalized medicine, pharmaceutical manufacturing, and drug safety monitoring.[44]

AI has improved the speed and accuracy of drug discovery, allowing for the identification of novel drug candidates, optimizing clinical trial designs, and facilitating the prediction of adverse drug reactions. Additionally, AI technologies are being integrated into clinical pharmacy settings for better medication therapy management, reducing medication errors, and supporting pharmacists in clinical decision-making.[45]

However, the integration of AI in pharmacy also presents challenges, such as the need for robust data privacy and security protocols, regulatory hurdles, and the risk of algorithmic bias. Addressing these issues will be essential for ensuring the safe and effective implementation of AI in pharmacy practice.[46]

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The authors declare that they have no know competing financial intrests or personal relationships that could have appeared to influences the work reported in this paper.

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