www.ijarp.com ISSN 2456-9992 Page: 01-34

International Journal Advanced Research Publications

Review Article

Volume: 02
Issue: 07

A COMPREHENSIVE REVIEW OF ARTIFICIAL INTELLIGENCE IN PHARMACY: APPLICATIONS, CHALLENGES, AND FUTURE PERSPECTIVES

Aniket Narayan Tompe[1*], Nayana G. Dhage[2], Pooja V. Wagh[2], Gayatri Pandit[2], Prof. Rushikesh G. Diware[2], Prof. Satish P. Shelke[2], Dr. Shirish Jain[3]

[1*&2]Department of Pharmaceutical Quality Assurance, Rajarshi Shahu College of Pharmacy, Buldhana, Maharashtra, India.

[3]Principal, Department of Pharmacology, Rajarshi Shahu College of Pharmacy, Buldhana, Maharashtra, India.

Article Received: 05 June 2026, Article Revised: 25 June 2026, Published on: 15 July 2026

***Corresponding Author: Aniket Narayan Tompe**

Department of Pharmaceutical Quality Assurance, Rajarshi Shahu College of Pharmacy, Buldhana, Maharashtra, India.

Doi: https://doi-doi.org/101555/ijarp.2633

ABSTRACT

The pharmaceutical sector has seen a change thanks to artificial intelligence (AI), which has improved medication research, discovery, and individualized patient care. Artificial Intelligence (AI) has improved productivity, precision, and creativity in the sector through machine learning (ML), deep learning, natural language processing (NLP), and robotic automation. This study aims to provide insight into the prospective and real-world uses of AI in a range of pharmaceutical domains. Clinical pharmacy, pharmaceutical biotechnology, pharmaceutical nanotechnology, pharmacognosy, medicinal chemistry, pharmaceutics, pharmacology and toxicology, pharmaceutical management, and economics are some of these disciplines.

The ability of AI models to be both interpretable and explicable is essential for their successful integration in the healthcare industry. AI applications must be open and honest about their decision-making procedures and underlying logic in order to win over healthcare practitioners. The numerous aspects and difficulties of XAI in the healthcare industry are systematically reviewed in our research. By dividing them into six different groups—feature-oriented methods, global methods, concept models, surrogate models, local pixel-based methods, and human-centric approaches—it seeks to analyze a variety of XAI approaches and their uses in healthcare. This study specifically highlights the importance of XAI in

tackling healthcare-related issues and emphasizes its important role in situations where safety is at stake.

KEYWORDS: Artificial Intelligence (AI), Explainable Artificial Intelligence (XAI), Machine Learning (ML), Deep Learning, Natural Language Processing, Drug Discovery, Personalized Medicine, Clinical Pharmacy, Pharmaceutical Biotechnology, Healthcare.

INTRODUCTION

Any task that a machine or software can perform that would otherwise require a human to employ intellect is referred to as artificial intelligence (AI). The goal of science and engineering is to create intelligent machines, especially ones that can recognize speech, make judgments, and translate between languages. The simulation of human intelligence by technology, especially computer systems, is known as artificial intelligence (AI). This includes learning, planning, self-correction, problem-solving, motion, manipulation, creativity, and knowledge representation. It is a branch of research and a set of computer techniques inspired by the way humans feel, remember, and reason through their bodies and neurological systems.[1]

In actuality, artificial intelligence has already influenced our way of life, either directly or indirectly, and is influencing the future of our planet. Even though digital assistants for smartphones, driver assistance systems, bots, text and speech translators, and systems that assist with personalized learning and product and service recommendations are all necessary, artificial intelligence (AI) has already permeated every aspect of our daily lives and profoundly changed how we live.[1] In many industries, artificial intelligence (AI) has become a cutting-edge technology. In the healthcare sector, in particular, AI has the potential to transform drug research and improve pharmacy procedures. The ongoing growth of AI, driven by advances in data science and machine learning, has made it easier to create novel answers to challenging problems in the pharmaceutical industry. The development of algorithms that can learn, adapt, automate procedures, and conduct complex data analysis is what supports the use of AI and opens the door to improved operational efficiency and decision-making.

Artificial intelligence can be divided into broad categories based on what it can do and how it can be used. "Narrow" or "weak" artificial intelligence refers to the development of technologies designed to do particular, repetitive tasks.[1]

In the healthcare field, "machine learning" is a popular strategy used. Recently, it has been applied in areas like predicting disease outbreaks and figuring out the best way to treat people in the context of developing tailored medicine. The use of machine learning to repetitive and often predictively modeled tasks has resulted in significant decreases in therapeutic and diagnostic errors commonly observed in human medical practice, as demonstrated by the aggregation of baseline data on patient- and disease-specific characteristics.[1]

SCOPE

A Comprehensive Review of Artificial Intelligence in Pharmacy" covers a lot of ground, including the many ways AI is used in the pharmaceutical industry, like in clinical trials, personalized medicine, drug development, and patient care. It looks at the pros, such faster processes and lower costs, as well as the big cons, like bias, data privacy, and regulatory hurdles. The review also looks at the future, including how AI could change personalized treatment plans, improve patient outcomes, and encourage research that crosses disciplines.

OBJECTIVE

Look at what we already know about how artificial intelligence is affecting the pharmacy industry, including its many uses (such as drug discovery and personalized medicine), the problems it causes (such as data quality and moral dilemmas), and the possible ways it could be used in the future. [3] Give an overview of AI technology, talk about the main problems they face, look at possible future paths, and give stakeholders useful information.

AI APPLICATION IN THE PHARMACEUTICAL INDUSTRY

AI can completely transform the pharmaceutical manufacturing industry through quality control, process automation, and predictive maintenance. It is also utilized in supply chain management to efficiently manage inventories, forecast demand, and optimize transportation. The second area of concentration will be on applying AI to improve patient outcomes. By analyzing clinical and genetic data, AI customizes medications for each patient, improving effectiveness and reducing side effects.[3]

Figure 1 AI Application in the Pharmaceutical Industry.

Artificial intelligence (AI) is changing businesses all around the world by making computers act like people. This technology lets machines learn, reason, solve problems, see, and understand language—things that used to require human thought. AI is changing the pharmaceutical sector in a big way. Its multiple uses have led to big improvements in patient care, production, clinical trials, drug discovery, and operational efficiency.[3]

DRUG DISCOVERY AND DEVELOPMENT

Drug discovery is the process of finding and making new drugs for sale. This process normally takes 15 years to finish. The first step in drug discovery is to pick a disease to target and find a target that could change the sickness. The next step is exploratory research, which uses a lot of screening tests to find HIT molecules, which are chemical compounds that could be able to bind to the target. After additional investigation, a chemical that can change the target's normal way of working and attaches to it in a precise and selective way is chosen. We refer to this molecule as the LEAD compound. After that, the lead molecule is refined to improve its ADME (absorption, distribution, metabolism, and excretion) characteristics and biological activity.

The medicine advances to the preclinical (formulation research and animal testing) and clinical stages if a promising chemical is found during screening. Before a medicine may be put on the market, regulatory agencies like the Food and Drug Administration (FDA) or the European Medicines Agency (EMA) must approve it after clinical trials are finished. Pharmacovigilance will be used to track the drug's safety throughout its distribution when it is put on the market.[2]

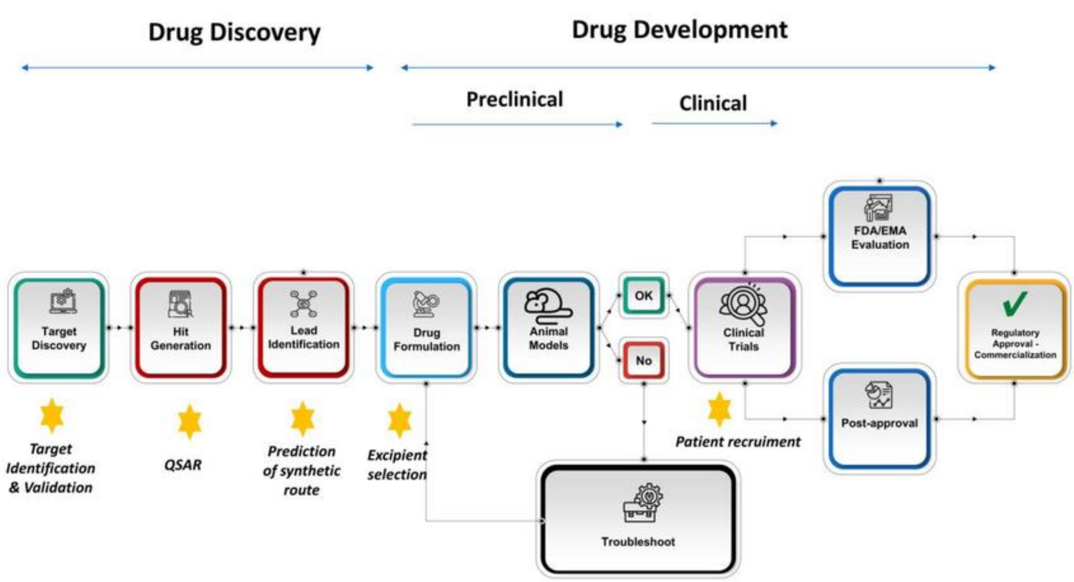

Figure 2 Drug Discovery and Development.

The enormous chemical space that needs to be investigated in order to find viable drug candidates is one of the main obstacles in drug discovery. Large chemical library screening using traditional methods is time-consuming, labor-intensive, and frequently yields few hits. However, machine learning algorithms used in AI-driven virtual screening techniques are able to quickly sort through enormous chemical compound datasets and forecast their biological activity against particular therapeutic targets. To rank the compounds with the best chance of being therapeutically effective, these algorithms can examine molecular interactions, physicochemical characteristics, and structural aspects. This can greatly speed up the optimization of the hit-to-lead process. Both supervised and unsupervised learning are used in machine learning algorithms.[3]

Since there are currently no viable treatments for a number of diseases or clinical conditions, drug research programs must still target these unmet clinical requirements. Proteins or pathways with potential therapeutic benefits are frequently discovered during early academic research; nevertheless, target selection may need additional validation before drug development can move forward. After hints are found, a thorough investigation is carried out to find a small-molecule or biological drug candidate. Before it can be sold commercially, it must pass preclinical testing and clinical trials. The costly drug development process frequently takes over ten years from discovery to approval. It should be mentioned that approval times and related expenses can differ. Drug development and discovery have traditionally relied heavily on computational methods. Time, computational cost, and reliability are some of the issues that still plague traditional computer techniques. Drug discovery uses molecular dynamics (MD) modeling to assess binding stability and protein–ligand interactions. Its potential for high work and time consumption is one of its main drawbacks. Medicinal chemistry currently makes extensive use of randomized procedures and large-scale high-throughput testing methodologies. To find molecules with the necessary characteristics, these techniques look at a large number of potential molecules. However, these approaches can be expensive and tedious and may often yield false results. It is true that similarity-based methods, such as ligand-based virtual screening (LBVS), exhibit notable "selectivity" in detecting different active compounds. Its propensity for false-positive detections is a drawback in "real" applications. Potential novel bioactive chemicals are not accurately predicted when drug research relies on trial-and-error testing. Therefore, the few conventional pharmaceutical testing methods have worked well in the past. Industrial research and development (R&D) continuously assess new technologies across the different research disciplines in order to speed up the discovery process. The process's constant delays and rising costs open the door for investments in extremely sophisticated technology, better manufacturing techniques, and creative research approaches for real results. These issues may be resolved by a variety of AI-based algorithms, including rule-based, scalable, reinforcement learning, and supervised and unsupervised approaches.[4\]

TARGET IDENTIFICATION

Big Data Analysis

By quickly evaluating enormous biological datasets (genomic, proteomic, and clinical) to find new disease-associated biological molecules or pathways—a job that has historically been difficult and slow—AI and machine learning transform drug target identification. By spotting intricate patterns, coming up with theories for novel therapeutic targets, expediting the target selection process, and even directing the creation of medication candidates that precisely modulate these targets, AI-powered techniques surpass conventional ways.

How AI works to select targets

AI algorithms, especially machine learning (ML) and deep learning, are skilled at processing and evaluating vast amounts of clinical data as well as multi-omics data (genomic, proteomic, and metabolomic).

Pattern Recognition: AI can find biological elements, such proteins or cellular pathways, that are crucial to a disease mechanism by spotting hidden patterns and intricate interactions within these datasets.

Knowledge Graphs: AI can construct knowledge graphs by looking at public databases and scientific literature. These graphs connect existing data to predict novel drug target-disease connections.

Predictive Modelling: AI models can use data from genome-wide association studies (GWAS) to guess which genes are most likely to be connected to a certain disease.

LEAD COMPOUND IDENTIFICATION

AI-driven lead compound discovery speeds up the drug development process by quickly going through enormous chemical libraries and utilizing machine learning and deep learning to guess which ones would be good drug prospects. AI models use chemical structures and biological data to make very accurate predictions about a compound's biological activity, "drug-likeness," and ADMET characteristics (absorption, distribution, metabolism, excretion, and toxicity). This leads to a big rise in hit rates and a drop in costs when compared to traditional experimental procedures. The Springer article says that this lets researchers focus on good ideas for turning them into drugs that could help with a wide range of diseases.[5]

The Application of AI to Lead Compound Recognition

Virtual Screening: AI systems can quickly search through huge chemical databases for substances that are thought to bind to a certain biological target protein that is connected to a disease. The link between quantitative structure and activity (QSAR). Using machine learning methods, it is possible to construct QSAR models that link a compound's chemical structure to its biological activity. This lets us guess how new compounds could behave. Artificial intelligence (AI) can predict a number of important properties of candidate molecules, such as their solubility, synthesizability, and ADMET (absorption, distribution, metabolism, excretion, and toxicity) characteristics. This helps prioritize compounds that are more likely to succeed in development.

Generative Models: Deep learning techniques, such as generative models, can produce whole new molecular structures with potentially desirable properties while also screening current libraries, thus expanding the chemical space for drug discovery.

Data Integration: AI may look for patterns and prospective lead compounds by combining and analysing complex datasets from many different fields, such as proteomics, genomics, chemical informatics, and clinical research.[6]

Drug Repurposing

AI-driven drug repurposing uses machine learning and AI algorithms to look at huge datasets (such genetic, molecular, and clinical data) and locate existing drugs that can be used to treat new ailments. This cuts down on development time and cost by a huge amount. This technique uses AI-powered prediction, screening, and validation steps to speed up the process of finding prospective pharmaceutical candidates for a wide range of conditions, from uncommon diseases to pandemics like COVID-19.[5]

Predicting Toxicity and Efficacy

AI employs machine learning and deep learning to look for patterns in big databases of chemical structures, biological tests, and patient data. This helps it guess how hazardous and effective medications will be. In the end, our predictive modelling makes medication safer and speeds up development by finding potentially dangerous compounds early on in the discovery process. This means that less expensive and time-consuming clinical trials and animal tests are needed.[6]

CLINICAL TRIAL

Clinical trial design

Artificial intelligence (AI) is changing how clinical trials are designed by predicting how people will respond to treatments, using electronic health records (EHRs) to automatically identify patients, and creating digital twins to make studies more personal and do away with the need for large placebo groups. This improves trial efficiency by saving time and money, choosing better candidates, and making treatments that are more accurate and effective, which leads to better patient results.

How AI Makes Clinical Trial Design Better

Finds the Right Groups of Patients: AI algorithms can automatically find patients who meet the exact inclusion and exclusion criteria for a trial by processing a lot of data from EHRs. This used to be a job that needed a lot of manual evaluation.

AI helps put patients into groups that are most likely to benefit from a certain treatment by looking at their characteristics. This makes it easier to recruit and choose patients.

Predicts how a patient may respond to a drug. AI-powered digital twins, which are virtual copies of specific patients, can predict how a patient's clinical measurements will change with different treatments. This helps doctors choose the best treatment for each patient by finding those who are most likely to respond well to a medication.

AI can construct personalized treatment arms by accurately predicting how well a drug will work for certain patients. This is different from the "one-size-fits-all" approach used in most studies. Digital twin technology lets you change a patient's treatment based on how they really reacted to it compared to how you thought they would react. This makes sure that the patient gets the best possible care.

Patient Recruitment and Monitoring

AI speeds up and improves the process of finding clinical trial patients by using algorithms to look at Electronic Health Records (EHRs) and other data to find qualified candidates based on complex criteria. This leads to more accurate matches and better representation. AI keeps participants in the program longer by giving them personalized support and engagement. It also collects data automatically for monitoring and checks patient data for safety and adherence. Because of this, trials are finished faster, costs go down, there are more types of trials, and patients can get new treatments faster.[9]

Using AI to Hire Patients

EHR Analysis: AI systems can save a lot of time and effort by looking through huge volumes of EHR data to discover the right patients. This is better than doing it by hand.

Personalized Matching: Algorithms use pattern recognition in patient data to locate people who not only meet the basic requirements but are also likely to obey the rules of the study.

AI can make trials more diverse and make sure that the results can be used to a wider range of people by using social media and community health records to reach out to people who are usually left out.

Automated Engagement: AI-powered tools can automate tasks like scheduling and answering patient questions, making the process more efficient for both patients and locations.

Using AI to Keep an Eye on Patients

Automated Data acquiring: AI agents can make the whole trial process easier by taking care of patient records and acquiring data automatically.

Continuous Monitoring: AI makes it possible to automatically and continuously watch patients, which can quickly find problems with adherence and safety alerts.

Predictive Analytics: Proactive patient retention management is made possible by machine learning algorithms that forecast patient engagement and adherence levels. Even though many businesses invest a lot of money in participant management to lower the risk of trial failure, it is challenging to choose and enlist the best candidates for clinical trials. Participant dropout and non-adherence frequently cause studies to be delayed, exceed budgets, or produce unusable data. It is estimated that 86% of all trials fail to meet recruiting deadlines, and enrollment problems account for nearly one-third of all phase III study failures.[8]

The machine If these issues are resolved early on, clinical trials may be shorter and the likelihood of failures unrelated to the medication under review is decreased. Here are a few ways that machine learning could help researchers cut down on errors.

In order to improve the selection of specific patient groups for trials, patient population data is analyzed to identify the characteristics of those who are most likely to benefit from the suggested treatment or intervention (often colloquially referred to as "responders"). improving the methods for finding and enlisting trial participants, for instance, by matching patients with studies using EHR data.

Numerous clinical trials are already utilizing AI-powered voice assistants for a range of standard monitoring duties, such as alerting patients to forthcoming appointments, monitoring patients' daily activities, improving communication between sites and sponsors, and increasing doctors' awareness. Since digital technologies are not constrained by the limitations of human intellect, they may simplify and enhance patient care. Simulation studies have demonstrated that using ML approaches improves trial participants' overall response rates and treatment allocation.[11]

Bias, in particular, can limit and skew ML results, making it difficult to use ML to identify more specific patient groupings. For example, if ideal patients are selectively selected using EHRs and other accessible data, enrollment may be unfairly skewed towards patient groups that have better access to healthcare and, thus, a larger chance of being chosen based on their healthcare data. Because they interact with the healthcare system less frequently overall, patients who live in underserved, rural, or otherwise inaccessible areas are less likely to be able to take part in this study. The results of studies with skewed enrollment may perform better in clinical trials, but they cannot be applied to the entire patient population.[11]

Theoretically, this could result in the approval of medications that only treat a small portion of the target population effectively. If face recognition software or other machine learning techniques are used to monitor trial participants and ensure they follow research guidelines, they will likely feel their privacy is being infringed. Choosing patients who have access to and are familiar with the necessary ML monitoring methods is one potential source of bias.

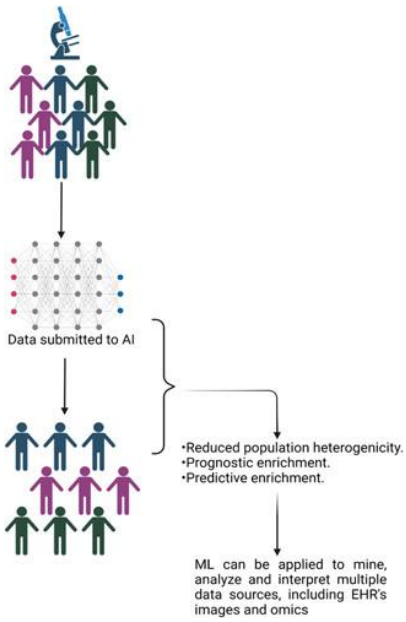

Figure 3 Use of AI in clinical trials. AI, artificial intelligence.

AI IN PHARMACY PRACTICE

Medication Management and Patient Safety

The absence of avoidable injury to a patient and the reduction of the risk of harm related to the medical procedure are the two main components of patient safety. There is some inherent danger associated with each step of the caregiving process. Patient safety issues and adverse events in healthcare settings have received more attention since the 55th World Health Assembly's 2002 proposal of resolution WHA55.18 on "Quality of Care: Patient Safety." Studies continue to show poor patient safety outcomes in spite of the safety activities and investments undertaken by commercial organizations, concerned institutions, and the federal and local governments.[16]

The Use of AI

Analysing Large Datasets: AI is capable of electronic processing enormous volumes of patient data, such as medication histories, health records (EHRs), and patient monitoring data, in order to uncover hidden patterns and early warning indicators of adverse drug reactions (ADRs).

Predicting Risk Factors: AI algorithms are able to forecast a person's likelihood of suffering an adverse drug reaction (ADR) by examining patient-specific data such as genetics, lifestyle, and pre-existing conditions.

Information Extraction from Unstructured Data: NLP enables AI systems to retrieve pertinent patient data from unstructured sources, such as reports and clinical notes, enabling more thorough safety monitoring.

Detecting Drug-Drug Interactions: AI is able to detect possible drug interactions, which is essential for reducing toxicity and enhancing patient safety.

Clinical Decision Support System (CDSS) AI in clinical decision support systems (CDSS) addresses important issues like data bias, model interpretability, regulatory compliance, and the requirement for strong clinician acceptance and training. It also highlights AI's potential to improve treatment outcomes, increase diagnostic accuracy, and streamline workflows. Machine learning, natural language processing, and deep learning are important AI technologies in this area that allow for risk prediction, individualized therapy recommendations, and insights from unstructured clinical material. To overcome present constraints and guarantee safe, efficient, and moral integration into clinical practice, future advances will concentrate on federated learning, ambient clinical intelligence, and enhanced human-computer interaction.[14]

Principal Advantages of AI in CDSS

Improved Diagnosis and Treatment: AI makes it easier to create individualized treatment plans based on patient data, decreases medical errors, and increases diagnostic accuracy. **Personalized Medicine:** AI-powered tools can suggest therapies based on a patient's unique traits, resulting in more precise and successful treatments. **Workflow Streamlining:** AI optimizes healthcare workflows and lowers clinician burnout by automating analysis and sending out timely alerts. **Greater Results:** In the end, integrating AI into CDSS leads to more affordable treatments, greater drug compliance, and better patient outcomes**.**

Adherence to Medication By using intelligent tools like conversational agents, smartphone apps, and predictive algorithms to monitor patient behavior, send personalized reminders, and provide customized interventions, artificial intelligence (AI) is revolutionizing medication adherence and ultimately improving health outcomes, lowering costs, and managing chronic diseases more pro-actively. Even though AI provides a strong, data-driven strategy, issues including patient trust, data privacy, and the requirement for clinically verified, ethically governed systems must be addressed for successful deployment.

How AI Enhances Adherence to Medication

Personalized Interventions: AI uses patient data analysis to pinpoint the causes of non-adherence, enabling the creation of tailored support plans, instructional materials, and reminders.

Smart Tools: Mobile applications and conversational agents (chatbots) provide round-the-clock assistance, respond to patient inquiries, and assist in managing side effects and prescription regimens.

Predictive analytics: AI can identify patients who are most likely to not comply to treatment plans, allowing medical professionals to proactively provide focused assistance before problems worsen.

Behavioural Monitoring: By using AI to track and validate medicine intake, tools such as video directly observed therapy (VDOT) improve accountability and offer useful information on patient behavior.

Better Communication: AI-powered tools can help patients and medical professionals communicate more effectively, which can result in more successful treatment regimens.[13]

Retail and Hospital Pharmacy Operation

Inventory Management

By evaluating real-time data and automating processes like reordering, artificial intelligence (AI) in inventory management optimizes stock levels, enhances demand forecasts, and streamlines supply chain operations. Reductions in overstock and stockouts, improved productivity, cost reductions, and improved customer satisfaction through proactive, data-driven decision-making and real-time monitoring are some of the main advantages.

How AI Enhances Inventory Control

Demand Forecasting: To reduce supply and demand mismatches, AI algorithms examine past sales data, market trends, and other outside variables to forecast future demand more precisely.

Real-time tracking: AI systems that are frequently combined with Internet of Things sensors monitor inventory levels in real time, giving constant insight into stock levels and movements.

Automated Replenishment: AI systems can automatically initiate reorders to replenish stock before it runs out based on current stock levels and anticipated demand.

Stock Optimization: AI ensures that firms carry the proper amount of merchandise by preventing both stockouts (missed sales) and overstocking (high storage costs, spoiling), which helps maintain ideal inventory levels.

Process Automation: AI reduces human error and frees up staff for higher-value jobs by automating repetitive, manual operations like order processing and stocktaking.

Unusual inventory levels or sales patterns can be identified by machine learning algorithms as signs of possible disruptions, theft, or damage.[12]

Making Decisions Based on Data

Businesses may make more proactive, well-informed decisions on supply chain strategy and inventory levels because to AI's ability to extract useful insights from massive datasets.[11]

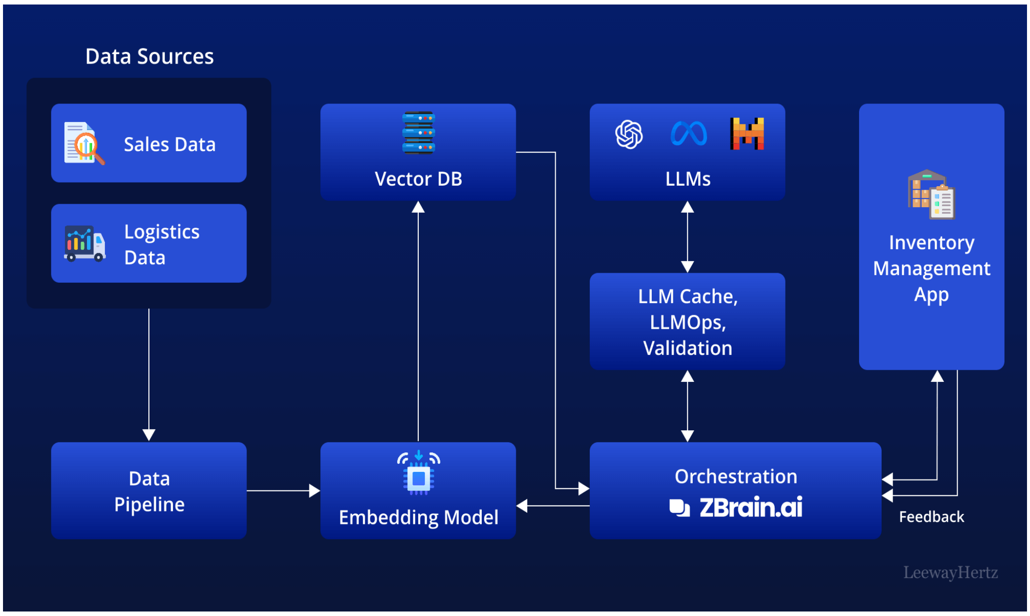

Figure 4 Making Decisions Based on Data.

Because AI can extract valuable insights from large datasets, businesses may be able to make more educated and proactive decisions about inventory levels and supply chain strategy.[16]

Reduced Pharmacist Fatigue

Automating routine tasks helps to minimize human fatigue and distraction, allowing pharmacists to focus on more complex and crucial patient-facing duties.[15]

Proactive Maintenance

AI can predict and anticipate system maintenance needs, preventing downtime and ensuring continuous operation.

Enhanced Accuracy

By detecting and fixing dispensing errors, AI algorithms lower the possibility of giving the wrong prescription or dosage. Enhanced Productivity AI minimizes manual labor and speeds up the dispensing process by automating repetitive processes like labelling, sorting, and counting.

Personalized Patient Care: AI examines patient information, such as genetics, lifestyle, and medical background, to assist in customizing drug regimens and dosages, which results in improved

Enhanced Safety for Patients

As an additional precaution, AI can notify pharmacists of any drug interactions or allergies by comparing prescriptions with patient medical records. Simplified Workflow: By integrating with other pharmacy systems, such inventory management and electronic health records, AI streamlines the entire process, from prescription to billing.

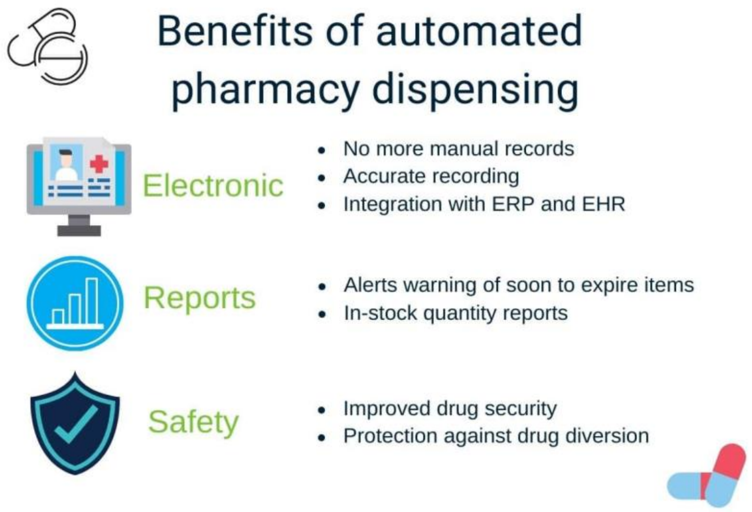

Figure 5 Enhanced Safety for Patients.

Counselling for Patients

By offering virtual support for diagnosis, treatment planning, and support—especially in mental health—and by increasing the patient experience through information availability and appointment scheduling, artificial intelligence is boosting patient counseling. Longer access and less administrative work are two advantages of AI, but it also raises questions about potential biases, the need for ethical governance, and the loss of human connection. A hybrid approach that enhances rather than replaces human therapists is crucial for integrating AI in counselling. To achieve a successful and moral integration, patients' needs and viewpoints must be taken into account.[17]

AI's advantages for patient counselling

Improved Access and help: Particularly in emergencies, AI-powered solutions can offer 24/7 access to basic counselling help, preliminary evaluations, and therapeutic interventions. Enhanced Patient Flow and Efficiency: AI can help with scheduling and patient triage, freeing up healthcare professionals to concentrate on complex care.

Customized Interventions: AI is able to examine user information and sentiment to customize treatment programs and approaches, enhancing participation and results.

Improved Patient Experience: AI technologies can assist control patient expectations and lower anxiety by providing clarity about appointment schedules and processes. **assistance for Particular disorders:** Patients can benefit from continuous monitoring and assistance, practice mental wellness approaches like cognitive behavioural therapy, and manage chronic disorders with the aid of AI-driven tools and applications.

Obstacles and Restrictions

Loss of Human Element: One major concern is the possibility of undermining the doctor-patient bond and losing the essential empathy, confidence, and individualized treatment that come from face-to-face communication.

Ethical and Social Concerns: Careful consideration must be given to matters such as data privacy, confidentiality, the possibility of incorrect diagnoses, and the innate biases in AI systems**.**

Complexity of Mental Health:

The intricate and subtle nature of mental health issues, which might manifest differently in different people, may be too much for AI to handle**.**

Patient Acceptance: Successful AI deployment requires taking into account patients' requirements and preferences, as not all patients feel at ease with AI in healthcare.[18]

DIFFICULTIES AND ETHICAL ISSUES

Data-Related Issues

The absence of defined formats, insufficient and diverse datasets, and data quality and reliability are some of the issues with AI for pharmacies. Concerns about data security and privacy, ethical issues surrounding algorithmic bias, the requirement for system interoperability, and difficulties acquiring huge, well-annotated datasets for AI model training are other crucial obstacles. Particular difficulties relating to data.

Data Reliability & Quality

Reliable, high-quality data is necessary for AI models. Inaccuracies and inconsistencies in pharmacy data can drastically weaken the effectiveness of AI models, no matter how advanced they are. Data Heterogeneity and Lack of Interoperability: Integrating and harmonizing data for AI applications is made extremely difficult by the fact that information comes from a variety of sources and formats (such as labs, clinical trials, and medical records.

Inadequate and Badly Annotated Datasets: Large, thorough datasets with the appropriate annotation are severely lacking, which makes it difficult to train sophisticated AI models for activities involving pharmacies, particularly medication development and discovery. **Data Security & Privacy**: Preventing breaches, leaks, and misuse is a significant concern due to the sensitive nature of patient data used by AI systems in healthcare. **Algorithmic Bias:** Inaccurate or unfair patient care and decision-making results may result from models that reinforce or even magnify biases in the data used to train AI algorithms. **Absence of Standards**: Effective communication and the full potential use of AI's capabilities are hampered by the lack of generally recognized standards for data interchange and AI use in pharmacy.[19]

The availability and quality of data

The availability of high-quality annotated datasets for model training is a major obstacle in AI-powered drug development. One major obstacle is data heterogeneity, which occurs when data originates from many sources including chemical structures, biological testing, and clinical trials. It can be difficult and time-consuming to integrate and harmonize these various data sources into a single format for AI training. Furthermore, the performance and dependability of the model can be significantly impacted by biases in the training data. For instance, the resulting model may have biases that restrict its accuracy and generalizability in practical applications if the dataset largely reflects a particular demographic or disease subset. Careful data curation, strong data pretreatment procedures, and the creation of strategies to reduce bias and guarantee data representativeness are all necessary to meet these obstacles.

The Difficulties with Regulation and Ethics

The Challenges of Ethics and Regulation

Data bias, which results in unequal care; "black box" AI models' lack of transparency and explainability, which undermines trust and accountability; patient data privacy and security issues arising from the use of large datasets; and intricate issues of liability when AI systems make mistakes are some of the main ethical and regulatory obstacles facing AI in pharmacy. In order to safeguard patient rights and encourage ethical adoption, regulations must change to guarantee AI systems are legitimate, dependable, and secure. This calls for frameworks for data governance, bias mitigation, and transparent accountability.

Challenges in Ethics

Bias and Fairness: AI algorithms developed on incomplete or non-diverse datasets have the potential to reinforce and even magnify current health disparities, denying underrepresented groups fair access to innovative treatments and diagnostics.

Security and privacy: AI systems need a lot of private patient information, which raises the possibility of security lapses, illegal access, and abuse that might erode confidence.

Explainability and Transparency: Because many AI models are intricate "black boxes," it can be challenging for regulators and pharmacists to comprehend how they make decisions. This undermines clinical application, accountability, and confidence.

Accountability and Liability: One of the biggest ethical and legal challenges is figuring out who is accountable (creator, user, or manufacturer) when an AI system makes a detrimental mistake or offers inaccurate advice.

Informed Consent and Patient Autonomy: It can be challenging to obtain genuine informed consent for the use of data and AI-assisted treatments, particularly when intricate data requirements clash with privacy rights.

Social and Cultural Impact: The quick adoption of AI may also lead to worries about pharmacy personnel losing their jobs and the moral ramifications of the technology's expanding impact on patient care. Regulatory Difficulties

Changing Regulations: New standards and updated recommendations are required because the regulatory frameworks in place are frequently insufficient to handle the particular difficulties presented by AI in pharmacy.

Data Governance and Oversight: To ensure privacy and avoid discriminatory results, regulators must set precise guidelines for how AI systems gather, use, and safeguard patient data.

Ensuring Safety and Reliability: To ensure the effectiveness, safety, and quality of AI-driven pharmaceutical applications, ranging from patient care to drug research, new regulatory approaches are required.

Domain-Specific experience: To assess AI systems that cut across several scientific domains and make sure they solve any potential legal, ethical, or discriminatory shortcomings, regulators and inspectors need domain-specific experience.

Proactive Governance: To guarantee that legislators can handle the ethically difficult situations raised by the application of AI in healthcare settings before they become pervasive issues, proactive governance is desperately needed.[20]

Integrations and Skill Gaps

AI integration in pharmacy is revolutionizing a number of fields, including patient care, pharmacy operations, clinical trials, and drug development. However, there are major obstacles to this change, including serious skill gaps among pharmacy personnel.

AI integration in pharmacy

AI integration is modernizing pharmaceutical workflows and changing the duties of pharmacists.

AI in the development and discovery of drugs

Quicker discovery: By analysing large datasets, AI speeds up the process of finding new medication candidates while cutting down on research expenses and time.

Predictive analytics: By using machine learning algorithms to forecast safety profiles, therapeutic efficacy, and molecular interactions, the time from lab to market is shortened. Repurposing medications: AI helps discover novel therapeutic applications for already-approved medications, which can hasten their distribution in emergency situations.

AI throughout the value chain for pharmaceuticals

AI in Logistics and Supply Chain

Pharmaceutical businesses are subject to strict rules and operate within a complicated supply chain network. AI is essential for increasing productivity, automating decision-making, and improving operations. AI reduces the risk of stockouts and excess inventory by precisely forecasting demand using machine learning algorithms fed with previous data. Additionally, the use of AI in predictive maintenance reduces unscheduled downtime. It forecasts equipment failures by evaluating sensor performance data, enabling planned repairs to be made before to malfunctions. According to a McKinsey & Company study, supply chain management AI technologies might cut forecasting mistakes by as much as 50% and overall supply chain expenses by 5–10%.[17]

DRUG DISCOVERY & TARGET IDENTIFICATION

Property Prediction/ QSAR

In artificial intelligence (AI), QSAR stands for Quantitative Structure-Activity Relationship (QSAR). Machine learning in particular is used to create predictive models that link the structure of a chemical substance to its physicochemical or biological qualities. Faster drug discovery, lead optimization, toxicity prediction, and the creation of materials with desired qualities are made possible by AI-driven QSAR, which predicts a compound's activity based on its structural traits.

The application of AI in QSAR data-driven modeling: Machine learning algorithms employ training data to discover intricate, implicit connections between molecular structures and their characteristics that conventional statistical techniques would overlook.

Increased predictive power: AI models, particularly ensemble-based techniques, can outperform single models in order to produce more robust and dependable forecasts of a compound's activity.

Feature extraction and selection: AI aids in the selection of the most pertinent chemical descriptors and features for property prediction, which is essential for creating precise models.

Applications of AI-powered QSAR therapeutic discovery: By forecasting the effectiveness and possible toxicity of novel compounds, AI-QSAR speeds up the identification of possible therapeutic candidates.

Lead optimization: By proposing structural changes that enhance desired qualities like activity, safety, or solubility, it aids in the optimization of current pharmacological leads.

Environmental effect prediction: AI-QSAR can forecast how chemical compounds will affect the environment, which helps designers create sustainable and eco-friendly materials for a range of uses.

Science of materials: Beyond the pharmaceutical industry, AI-QSAR can be used to design and forecast the characteristics of novel materials, such sensors.

AI's Significance for QSAR Efficiency

AI allows for quick in silico screening of chemicals, which drastically cuts down on the time and expense involved with conventional experimental methods.

Complexity: AI can manage big, complicated datasets and spot subtle connections that humans find hard to notice, which results in more precise models.

Innovation: A potent multidisciplinary strategy that is transforming industries like drug development and sustainable materials design is the combination of AI and QSAR.[24]

Design De Novo

Creating new medications is a difficult and complex task that is made more difficult by the quickly changing needs for healthcare around the world. One promising method to quicken and improve this process is de novo drug design. Rapid and semi-automatic design and optimization of drug-like compounds is now possible because to the recent development of Generative Artificial Intelligence (AI) algorithms, which has raised awareness of the subject and sparked a paradigm change. The influence of de novo drug creation is examined in this review, which also highlights the hopeful advancement of Active Learning (AL) and both conventional approaches and the recently developed generative algorithms. It is a unique location.

emphasis on their use in the development of cancer drugs, where there is a pressing demand for new therapeutic agents. A new era in the quick discovery of novel medications is heralded by the possible combination of these AI technologies with well-established computational and experimental techniques. It is meant for professionals in related fields and offers a thorough introduction to AI-driven de novo drug design of small organic molecules. However, despite the encouraging advancements and noteworthy successes, these technologies have limitations that call for careful consideration and further development. It seeks to provide a comprehensive grasp of the present situation and potential future developments of these cutting-edge drug discovery methods.

Screening Virtually

AI-powered virtual screening (VS) is a computational approach to drug discovery that predicts the binding affinity, pharmacokinetic characteristics, and toxicity of large chemical libraries using AI, specifically machine learning and deep learning, to swiftly and effectively identify possible drug candidates. These AI algorithms estimate a molecule's eligibility as a therapeutic candidate by evaluating compound structures and training on large datasets. This greatly reduces the need for costly and time-consuming wet-lab tests and speeds up the discovery of prospective hits for additional research.

The Operation of AI Virtual Screening

Data-Driven Approach: A variety of datasets, such as current chemical databases, research articles, and experimental data, are used to train AI models.

Predictive Modeling: AI algorithms learn to forecast important characteristics of substances, such as their toxicity, solubility, and capacity to bind to a target protein, in place of doing physical trials.

Large-Scale Screening: When compared to more conventional, slower techniques, these models are able to quickly screen millions of commercially accessible chemicals.

molecule Prioritization: Researchers can rank the most promising compounds for experimental testing by using the output, which is a score indicating the likelihood that a molecule will become a suitable drug candidate.[17]

Knowledge Graph

Integration of Structured Data: Knowledge graphs combine dissimilar data from multiple sources (such as scholarly publications and experimental findings) into a single, organized representation.

linkages and Entities: They employ "edges" to define the confirmed, significant linkages between entities (e.g., a medicine that targets a specific protein) and "nodes" to represent entities such as drugs, proteins, genes, and diseases.

AI-Driven Insights: These graphs are subjected to sophisticated AI and machine learning algorithms in order to

Forecast Connections: To find new, undiscovered links between entities, use link prediction.

Determine Drug Targets: Use gene-disease-drug correlations to rank possible therapeutic targets.

Allow Drug Repurposing: By methodically examining the relationships between existing, licensed medications inside the graph, discover new applications for them.

Important Uses

Target Prioritization: Determine which genes or proteins are most promising to target for a certain disease and rank them.

Drug repurposing: Reduce development time and expenses by identifying current medications that may be useful against novel ailments.

Mechanistic Understanding: Examine how elements interact inside the graph to uncover intricate biological processes and causes of medication resistance.

Data interpretation: Give large datasets context and meaning to help researchers better understand and use them.

DEVELOPMENT OF PREFORMULATING AND FORMULATION (QbD)

Optimization of Composition and Excipients

AI in Excipient Selection and Optimization The choice and optimization of excipients is a crucial part of a successful pharmaceutical formulation since they greatly affect the drug's stability, bioavailability, patient acceptance, and manufacturing viability. Historically, formulation scientists' expertise, empirical methods, and iterative testing have been the primary determinants of excipient selection. Due to the increasing complexity of modern dosage forms and the growing demand for development routes that are both time- and cost-efficient, artificial intelligence (AI) has been integrated into formulation science, namely in the rational selection and optimization of excipients. AI can evaluate large, multidimensional datasets, particularly ML techniques (Mol2vec + molecular descriptors + stacking), with good accuracy (AUC 0.93). These algorithms can uncover hidden patterns and non-linear correlations that govern the performance of excipients. These models can predict how excipients and the API, together with other formulation components, will interact under a range of process and environmental conditions. Such predictive capabilities could greatly reduce the requirement for extensive wet-lab testing and expedite the development of trustworthy formulations.[19]

Performance of Biopharmaceutics

According to McKinsey & Company and Scilife reports, "biopharmaceutic performance" refers to how well a drug behaves and performs in biological systems. Artificial Intelligence (AI) is being used to improve this by speeding up drug discovery, forecasting drug efficacy, and streamlining manufacturing processes in the biopharmaceutical industry.

How AI Improves the Performance of Biopharmaceutics

Enhanced Drug Discovery: AI systems examine enormous datasets to find possible therapeutic candidates and enhance their molecular structure, which expedites the process of discovering efficacious treatments.

Better Drug Efficacy and Safety: AI can forecast a drug's efficacy and possible safety issues by evaluating biological data, which helps to introduce safer and more efficient medicines to the market.

Optimized Manufacturing and Operations: AI can improve productivity and cut costs in biopharmaceutical operations by streamlining everything from drug research to manufacture.

Enhanced Pharmacovigilance: Artificial intelligence (AI) systems can automatically evaluate reports of adverse medication events, enabling a quicker and more precise assessment of drug safety in practical settings.

Personalized medicine: AI can assist in creating more individualized and successful treatments for patients by evaluating enormous volumes of patient data, hence improving patient outcomes.

Complex Form of Dosage

New Technologies in Artificial Intelligence (AI) for Creating Pharmaceutical Dosage Forms

Creating safe and effective dosage forms while meeting stringent regulatory requirements is a never-ending challenge for the pharmaceutical business. This procedure has historically mostly relied on time-consuming and tedious trial-and-error techniques. But artificial intelligence (AI) is becoming a more potent instrument that could completely change how pharmaceutical dosage forms are created.

Here are some particular instances of how artificial intelligence is being applied to the creation of various pharmaceutical dosage forms:

AI can be used to forecast the stability, bioavailability, and rate of dissolution of oral solid dosage forms, including tablets and capsules.

Injectable dosage forms: To guarantee the stability and effectiveness of injectable dosage forms, such as suspensions and solutions, artificial intelligence (AI) can be utilized to optimize formulation.

Topical dose forms: AI can be used to create more user-friendly and effective topical dosage forms, like ointments and creams. AI can be utilized in personalized medicine to create dosage forms that are specific to each patient's need.

Verification

A statistical technique for estimating machine learning models' proficiency is cross-validation. Because it is simple to use, easy to comprehend, and produces skill estimates that are typically less biased than other approaches, it is frequently used in applied machine learning to compare and choose a model for a particular predictive modeling problem. A simple introduction to the k-fold cross-validation process for assessing machine learning model skill is provided in this lesson.[18]

DEVELOPMENT OF ANALYSIS AND QUALITY ASSURANCE

ML + Chemometrics

Since chemometrics is a particularly effective technique for analyzing vast amounts of data, its application in food studies—and not just food studies—has started to gain more significance. When it comes to honey, chemometrics is typically utilized in conjunction with proven analytical techniques to evaluate honey authenticity and quality control. Research on how processing and storage changes affect honey quality is uncommon, but it has been steadily growing over the past ten years. This research has focused on new techniques to maintain honey quality, like high-pressure treatment or ultrasound. The use of chemometrics to assess honey quality during processing and storage has advanced over the past few years, as this review demonstrates. Along with the key features of certain popular chemometric techniques, the benefits of applying chemometrics to evaluate honey quality during processing and storage are discussed. The use of chemometrics to distinguish honey samples based on changes in their properties throughout processing and storage has proven to be effective.

Fault/ Drift Detection

The critical process of determining when an AI model's performance deteriorates over time as a result of modifications to the statistical characteristics of its input data or the underlying linkages between data and outcomes is known as fault/drift detection. Maintaining model correctness, dependability, and fairness in dynamic real-world situations requires this monitoring, which is frequently accomplished by automated statistical testing and model performance monitoring. This allows enterprises to retrain models and guarantee reliable AI systems**.**

PREDICTIVE MODELLING FOR GMP MANUFACTURING AND PROCESS ANALYTICAL TECHNOLOGY (PAT)

PAT: What is it?

Real-time Quality Assurance: PAT is a regulatory framework in the pharmaceutical sector that monitors product and process parameters in real-time, going beyond conventional batch-end testing.

System for Understanding: It consists of a system for planning, evaluating, and managing production procedures by means of prompt assessments of vital performance and quality characteristics.

Tools: During manufacturing, PAT collects sophisticated, multivariate data using in-line and online instruments, including Raman and NIR spectroscopy.

How Does PAT Use Predictive Modeling?

Data Interpretation: PAT tools collect complicated instrument data, which is then interpreted using predictive modeling, including chemometrics and multivariate analysis (MVA).

Creating Relationships: Predictive models create connections between critical process parameters (CPPs) and critical quality attributes (CQAs) by testing and data analysis. **Real-time Quality Prediction:** These models subsequently make it possible to forecast process results and final product quality in real-time.

Advantages of Predictive Modeling and PAT in GMP Manufacturing

Better Product Quality: Consistent, high-quality products are the result of real-time quality assurance.

Decreased Time and Costs: o Advantages include shorter cycle times, lower product development costs, and quicker time to market for new products.

Process Understanding and Control: Manufacturers are able to adopt a strong, scientifically grounded approach to control and optimization as a result of gaining a deeper understanding of their processes.

Predictive Upkeep

Real-time data and sophisticated analytics are used in predictive maintenance to forecast when equipment is likely to break. By continuously monitoring machine performance indicators like temperature, vibration, and fluid levels, predictive maintenance algorithms can spot trends and abnormalities that point to an imminent failure.

Condition-based monitoring is a predictive maintenance strategy in which sensors gather information on the operation and health of equipment. This data is analyzed by machine learning to give maintenance workers early warning indicators of possible problems. Predictive maintenance has the benefit of increasing productivity since it helps businesses cut down on needless maintenance and prevent expensive unscheduled equipment downtime. Forecasting

By avoiding premature breakdowns and streamlining maintenance plans, maintenance can increase the lifespan of assets. Selecting the Appropriate Strategy.

Digital Twins

From a machine or product to production facilities, plants, or even the entire supply chain, a digital twin is a digital version of a physical asset or process that changes over time.

The Digital Twin reduces the need for physical prototypes by fusing the real and digital worlds to help define and optimize the product and production system before investing in physical assets.

PERSONALIZED THERAPY & CLINICAL PHARMACY

Dose Individualization

Customization of Doses

For ages, doctors and other healthcare professionals have sought to individualize drug therapy, which is defined as adjusting medication choices and dosage for each patient. The foundation for personalization is a knowledge of the disease's pathophysiology, the drug's mode of action, and exposure-response correlations. Individualization can be achieved in a variety of ways, including therapeutic drug monitoring, population (sparse sample) pharmacokinetics, bacterial sensitivity, lowest effective doses, and, more recently, pharmacogenomics. Optimizing a drug's effectiveness, reducing its toxicity, or both are the objectives of individualization. Drug-disease-trial models and simulation have helped integrate data from numerous domains as databases and technology have advanced. A mechanistic approach to individualization has been made possible by physiology-based pharmacokinetic (PBPK) models, and individualization has also been made possible by clinical trial designs like enrichment. Future approaches to achieving individualization will include "-omics" technology, vaccinations, ex vivo gene therapy, and so-called "diseases-in-a-dish."[26]

Medication Safety

Safety of Medication

AI-powered automated dispensing systems can improve the accuracy and efficiency of medication dispensing by detecting potential medication errors, helping with clinical decisions during order verification, and making sure the right doses and dosage forms are given to the right patient at the right time.

Pharmacovigilance

Signal Detection: By automating data processing, analyzing large datasets, and spotting patterns in real-time, artificial intelligence (AI) and machine learning (ML) revolutionize pharmacovigilance (PV) signal detection. This allows for the faster and more accurate detection of possible adverse drug reactions (ADRs) than with manual methods. Natural Language Processing (NLP), which processes unstructured data from sources like social media and medical records, and sophisticated algorithms like Random Forest and Deep Learning, which are used for predictive modeling and intricate pattern recognition, are important AI technologies. There are still issues with data quality, model transparency, integration with current systems, and guaranteeing ethical use and regulatory compliance while improving efficiency and patient safety.

AI/ML Automated Data Processing Enhances Signal Detection AI significantly speeds up signal detection by automating the collection, cleansing, and analysis of data from a range of sources, including social media, electronic health records (EHRs), and unplanned reporting.

Improved Accuracy & Real-Time Analysis: Machine learning algorithms increase accuracy, allow for near real-time monitoring, and expedite the discovery of safety signals by identifying subtle patterns and correlations that human analysts might miss.

Better Predictive Skills: Proactive steps to reduce hazards before they become serious public health concerns are made possible by AI-driven predictive modeling, which can predict possible ADRs.

Integration of Diverse Data Sources

To provide a more thorough understanding of drug safety, AI may combine and evaluate data from several sources, or multi-modal data.

Advanced Recognition of Patterns: To evaluate unstructured data and find intricate patterns in safety data, methods like natural language processing (NLP), text mining, and algorithms like decision trees, random forests, and deep learning networks are employed.

NLP Mining NLP-powered AI in pharmacovigilance (PV) automatically detects, evaluates, and prevents adverse drug occurrences and safety signals by using machine learning to scan large volumes of unstructured text data, including social media posts and clinical trial reports. Through this connection, the pharmaceutical and life sciences sectors can improve patient safety, speed up drug discovery, and ensure regulatory compliance by converting manual procedures into more effective, real-time systems.[21]

The use of AI and NLP in pharmacovigilance

Data Extraction: From vast amounts of unstructured data, such as medical records, patient information, regulatory documents, and social media posts, which are replete with actual drug-related problems, natural language processing (NLP) techniques extract important information.

Adverse Event Detection: AI models use natural language processing (NLP) to find patterns and correlations in this data that could point to possible safety issues or adverse drug events (ADEs), frequently before they are noticed by conventional techniques.

Clinical Trial Optimization: By evaluating patient data to find homogeneous groups and provide prognostic and predictive enrichment, AI can enhance clinical trial design and patient selection.

Real-time Monitoring: NLP makes it possible to analyze clinical trial data in real-time, which speeds up the identification of trends and makes it possible to make better decisions that will benefit patients.

Regulatory Compliance:

By speeding up the processing and submission of adverse event data to health authorities, AI and NLP assist businesses in adhering to regulatory standards.

FUTURE DIRECTION

Personalized Medicines

AI is transforming personalized medicine by combining and evaluating large amounts of complicated patient data, such as genetic, clinical, and lifestyle data, to deliver individualized diagnoses, forecast disease risks, improve treatment regimens, and speed up drug discovery. Though there are still issues with data privacy, cost, interdisciplinary collaboration, and regulatory developments to fully realize its potential, machine learning and deep learning algorithms are able to detect minor trends and develop customized treatment regimens.[20]

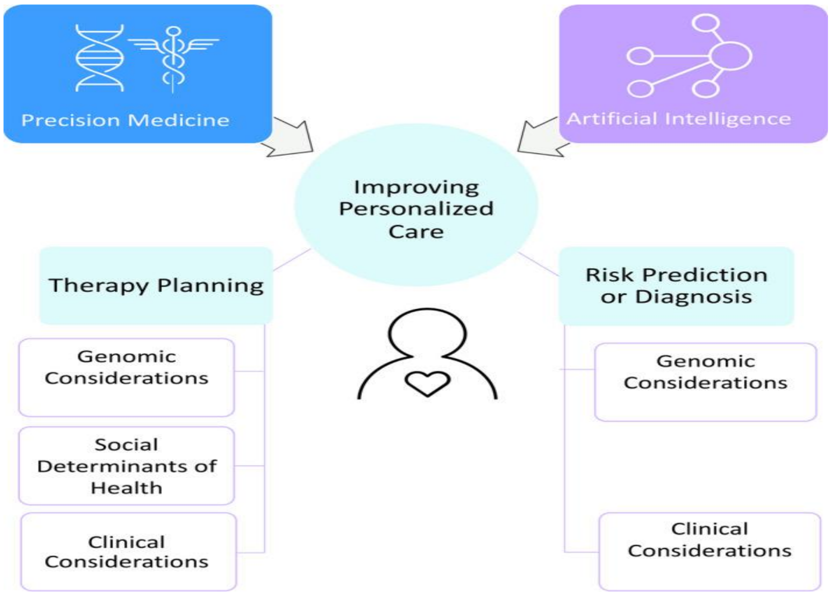

Figure 6 Personalized Medicines.

Predictive Analysis

To find trends, foresee actions, and project future events, predictive artificial intelligence (AI) uses statistical analysis and machine learning (ML). Predictive AI is used by organizations to forecast future events, risk exposure, causality, and more. Predictive analytics has long been used by analysts in organizations to make data-driven choices. However, because machine learning algorithms have access to so much data, predictive AI technology can speed up and improve the accuracy of statistical data analysis. In order to arrive at its conclusions, predictive AI examines thousands of variables and maybe decades' worth of data. Organizations can use these forecasts to get ready for emerging trends.[27]

Predictive AI is commonly mistaken for descriptive or prescriptive analytics. While predictive analytics helps organizations predict what is likely to happen, descriptive analytics helps them understand why something happened in the past. Prescriptive analytics suggests steps a company may take to ensure certain results occur.

In many businesses, predictive AI is utilized to improve decision-making and provide insights into consumer behavior. By generating dependable, precise projections, it may anticipate anything from mechanical problems to supply chain interruptions to customer attrition, allowing for proactive planning.

AI human cooperation

AI in human collaboration is a strategic alliance between artificial intelligence and human intelligence that uses their complimentary skills to produce better results. While AI is excellent at processing data, identifying patterns, and automating tasks, humans are better at critical thinking, creativity, and emotional intelligence. This collaboration boosts productivity, facilitates better decision-making by analyzing and interpreting data, and stimulates innovation in a number of industries, including healthcare, finance, and customer service.

How AI and Humans Work Together

AI offers speed, accuracy, and the capacity to analyze large datasets, while humans contribute special abilities like creativity, contextual awareness, and ethical reasoning.

Common Goals: The objective is to produce outcomes that surpass the sum of the contributions made by each individual human or artificial intelligence.

Integrated skills: To accomplish tasks, resolve issues, and generate new information, this partnership seamlessly combines human expertise with machine skills.

Advantages of Human-AI Cooperation

Increased Productivity and Efficiency: AI can manage monotonous and repetitive jobs, freeing up people to concentrate on more intricate, strategic, and imaginative endeavors. Better Decision-Making: AI produces insights by analyzing vast amounts of data, which people then interpret to arrive at morally sound conclusions.

Increased Creativity

New ideas and solutions can be created more successfully by fusing human creativity with AI's data-processing capabilities.

Enhanced Precision and Dependability

Though human oversight is essential, AI can help in domains like healthcare by evaluating complicated data, including medical pictures, to support more accurate diagnoses.

AI Types in Human-AI Cooperation Human-AI cooperation can be facilitated by a variety of AI system types, each having special strengths and weaknesses.

Machines that react: These AI systems are incapable of learning or adapting; instead, they base their judgments on pre-established rules. They work well for jobs that call for predictable and consistent answers, but they are not adaptable enough to deal with novel or unexpected circumstances.

Limited Memory AI: These AI systems may learn from experience and make judgments in real time based on historical data. By examining past data and modifying their behavior accordingly, they can gradually improve their performance.

Theory of Mind AI: These AI systems use machines to comprehend the intents and feelings of people. Although it is still in its infancy, this kind of AI seeks to build more socially conscious and sympathetic systems that can communicate with people more naturally and intuitively.

Self-Aware AI: Although this kind of AI is still theoretical, these AI systems are conscious and self-aware. If self-aware AI is developed, it has the potential to completely transform human-AI cooperation by giving computers a greater understanding of and ability to predict human needs and actions.[23]

CONCLUSION

According to a number of studies, artificial intelligence is revolutionizing pharmacy by providing more individualized patient care, simplified workflows, and safer medication administration. However, achieving this potential requires overcoming several obstacles, including upfront expenses, training requirements, data integrity, ethical issues, and regulatory limitations. The pharmacy profession must invest in "pharmaco intelligence," encourage interdisciplinary collaboration, dedicate to rigorous validation, and guarantee strong, transparent frameworks that put patient safety and trust first in order to fully realize AI's promise.

REFERENCES

1. Artificial intelligence (AI): what is it? The simulation of human intelligence processes by machines, particularly computer systems, is (n.d.). Quora.
2. https://vadlamudidhyanamalikasspace.quora.com/Artificial-intelligence-AI-what-is-it-The-simulation-of-human-intelligence-processes-by-machines-particularly-comp.
3. Rykov, M. Y. (2022). A survey of papers on the development of personalized medicine. *Gig Zdravko khranenniiai Astor Med Prowl Sistani, 30(6), 1211-121.
4. Distribution Logistics. (n.d.). https://www.meegle.com/en_us/topics/fmcg/distribution-logistics
5. The Invisible Revolution: How AI is Changing Everyday Life https://medium.com/horizon-hub/the-invisible-revolution-how-ai-is-changing-everyday-life-dc6e9a556b9c
6. 8 Ways AI is Changing Modern Mobile Games For The Better | Best Mobile App Awards Blog. (n.d.). BMAA. https://bestmobileappawards.com/blog/8-ways-ai-is-changing-modern-mobile-games-for-the-better
7. Torus, J., De Choudhury, M., Lee, E. E., et al. (2021). Clinical applications, obstacles, enablers, and artificial wisdom of artificial intelligence in mental health treatment. *Psychiatric Services*, 72(9), 856–864. https://doi.org/10.1176/appi.ps.202000440
8. Chalasani, S. H., Patil, V., Ramesh, M., Syed, J., & Kumar, T. M. P. (2024). An overview of the research on artificial intelligence in pharmacy. *Iranian Journal of Pharmaceutical Research*, 23(1), e150510. https://doi.org/10.5812/ijpr-1505
9. Elhaddad, M., & Hamam, S. (2024). AI-powered clinical decision support systems: An ongoing exploration of potential. *Cereus*, 16(4), e57728. https://doi.org/10.7759/cureus.57728
10. Benziger, C. P., Roth, G. A., & Moran, A. E. (2016). The Global Burden of Disease Study and the preventable burden of noncommunicable diseases. *The Lancet*, 388(10053), 1006-1020. https://doi.org/10.1016/S0140-6736(16)31060-0
11. Perez, H. D., et al. (2021). Algorithmic techniques to optimize inventory management. *Methods*, 9(1), 102. https://doi.org/10.3390/methods9010102
12. Chopra, H., Annu, N., Shin, D. K., Munjal, K., Priyanka, N., Dhama, K., & Emran, T. B. (2023). Revolutionizing clinical trials: the role of AI in accelerating medical breakthroughs. International Journal of Surgery, 109(12), 4211–4220. https://doi.org/10.1097/js9.0000000000000705

13. A review of Explainable Artificial Intelligence in healthcareAuthor links open overlay panel Zahra Sadeghi
14. Mottaghi-Dastjerdi N, Soltans-Rezaee-Rad M. Advancements and Applications of Artificial Intelligence in Pharmaceutical Sciences: A Comprehensive Review. *Iran J Pharm Res*. 2024;23(1): e150510. doi:10.5812/ijpr-1505
15. H. Allam, n.d. Artificial intelligence's function in pharmacy. Ball State University's College of Communication, Information, and Media are home to the Center for Information and Communication Sciences.
16. Quazi, M., Kamil, Q., Wasil, Q., Ahemad, H. A., & Khan, G. J. (n.d.). A review on artificial intelligence in pharmacy. Akkalkuwa, Maharashtra, India's Ali-Allana College of Pharmacy, run by J.I.I.U.
17. AI governance in the pharmaceutical sector: from research to delivery Author links cause the overlay panel to open. Rashi Jain and Stephanie Pasas-Farmer
18. AI-powered advancements in the pharmaceutical sector: streamlining business processes and drug discovery Author links cause the overlay panel to open. Jaskaran Deepak Yadav, Ankita Thakur, and Preet Singh Saini
19. Coverage of k-fold cross validation and other splitting strategies. (2023, January 26). DeepLearning.AI. https://community.deeplearning.ai/t/coverage-of-k-fold-cross-validation-and-other-splitting-strategies/263017
20. Pharmaceutics-16-01328. (n.d.). Scribd. https://www.scribd.com/document/806264376/pharmaceutics-16-01328
21. A mini-review of artificial intelligence in rare disease medication repurposing Cortial Lucas 1, 2, *, Montero Vincent
22. A scoping analysis on the use of AI to improve clinical trial recruitment and retention Chen Yang 1, Xiaohan Lu
23. Transforming clinical trials: AI's contribution to speeding up medical advancements Annu b, Dong K Shin b, *, Kavita Munjal c, Priyanka d, Kuldeep Dhama e, Talha B Emran, and Hitesh Chopra
24. Artificial intelligence-based de novo drug design: by David Crucitti
25. About using artificial intelligence for virtual screening Rahul Ravichandran 1, Francesco Gentile 1, Thanawat Thaingtamtanha 1.
26. A Calm Overview of k-fold Cross-Validation on October 4, 2023, Jason Brownlee wrote in Statistics

27. Lesko LJ, Schmidt S. Individualization of drug therapy: history, present state, and opportunities for the future. Clin Pharmocol Ther. 2012 Oct;92(4):458-66. Doi: 10.1038/clpt.2012.113. Pub 2012 Sep 5. PMID: 22948891.
28. Prescriptive Analytics: Definition & Benefits. (2025, July 15). Simpler. https://www.simpplr.com/glossary/prescriptive-analytics/
29. Perspectives on the Current Use of Chemometrics in Bee Honey Quality Assessment and Characterization Throughout Processing and Storage Tarapoulouzi, Maria 1, *, †, Monica Mironescu 2, *, Drouza Chryssoula 3.
30. Wiley.com/Doi/abs/10.1038/clpt.2012 https://ascpt.onlinelibrary.wiley.com doi/abs/10.1038/clpt.2012 https://ascpt.onlinelibrary.wiley.com
31. Optimizing Formulations and Excipients with Artificial Intelligence: Transforming the Development of Pharmaceutical Products Amrendra Anurag4, Mukesh Kumar Singh3, Gurdeep Singh2, and Pratap Yadav
32. Hansen, R. W., Grabowski, H. G., & DiMasi, J. A. (2016). New R&D cost estimates for innovation in the pharmaceutical sector. *Journal of Health Economics*, 47, 20–33. https://doi.org/10.1016/j.jhealeco.2016.04.001
33. AI for Pharmacist #7: AI in Pharmaceutical Dosage Form Development Choudhari Yogesh [Linkedin]
34. How artificial intelligence is utilized in predictive maintenance: https://www.neuralconcept.com/post/
35. Digital-twin.html?ac https://www.siemens.com/global/en/products/automation/topic-areas/digital enterprise
36. Drug Delivery and Discovery Using Artificial Intelligence (AI): Transforming Personalized Medicine Serrano, Dolores R. 1, 2, *, Aytug Kara 1, Baris Ongoren 1, Jesus A. Simon 1, Greta Tomietto 1, Chrysi Rapti 1, Helga K. Ruiz 1, Satyavati Rawat 3, Dinesh Kumar 3, Aikaterini Lalatsa
37. Williams, B., Munir, U., Bajwa, J., & Nori, A. (2021). Artificial intelligence in healthcare: Revolutionizing medical practice. Future Health Journal*, 8, e188-194. https://doi.org/10.1016/j.fhj.2021.05.002
38. Sadeghi, Z. (2023). A review of Explainable Artificial Intelligence in healthcare. *Journal of Healthcare Algorithmic techniques to optimize inventory management (Perez HD et al., 2021). Methods 9(1):102 Article Algorithmic Approaches to Inventory Management Optimization