

## Research Article

# ARTIFICIAL INTELLIGENCE IN PHARMACY

Ruchita Savaniya<sup>1\*</sup>, Afrid Vahora<sup>1</sup>, Saloni Parmar<sup>1</sup>, Dr. Hina Bagada<sup>1</sup>

Department of Pharmaceutical Quality Assurance

A. R. College of Pharmacy & G. H. Patel Institute of Pharmacy, Vallabh Vidyanagar, Anand, Gujarat,  
India. 388120

### ARTICLE INFO

**Article history:**  
**Received::** 30/07/2025  
**Revised::** 04/08/2025  
**Accepted::** 04/08/2025

**Key Words:** AI,  
Machine learning,  
deep learning, drug  
discovery,  
application

**Please cite this  
article as:**  
Savaniya R., et al,  
ARTIFICIAL  
INTELLIGENCE  
IN PHARMACY,  
7(2), 48-66

### ABSTRACT

Artificial Intelligence (AI) is a branch of computer science focused on enabling machines to mimic human behaviour, including learning and problem-solving. Originating from Alan Turing's inquiries about machine intelligence, the term "AI" was coined in 1956 by John McCarthy. AI systems are categorized by capabilities into Weak/Narrow AI, General AI, and Super intelligent AI. Key subfields include Machine Learning (ML) and Deep Learning (DL), which utilize algorithms and neural networks to analyse data. In healthcare, AI significantly impacts drug discovery, personalized medicine, and cancer treatment by enhancing early detection and improving therapeutic strategies. Despite its potential, challenges such as bias, data privacy, and integration with existing systems persist. However, collaborations between pharmaceutical companies and AI firms are advancing drug development and personalized treatments, as seen during the COVID-19 pandemic. Proper implementation of AI necessitates ongoing human oversight and robust data management practices.

©2025 Published by International Journal of PharmaO<sub>2</sub>. This is an open access article.

\* **Corresponding Author-** Savaniya R., et al, Department of Pharmaceutical Quality Assurance, A. R. College of Pharmacy & G. H. Patel Institute of Pharmacy, Vallabh Vidyanagar, Anand, Gujarat, India, [savaniyaruchita@gmail.com](mailto:savaniyaruchita@gmail.com)

### Introduction:

#### 1. Introduction for Artificial Intelligence

Artificial Intelligence refers to those branches of computers that deal with smart systems who can perceive, analyse, and respond to various inputs. While this sounds much like human intelligence through our capabilities to think, reason out, and make decisions, AI

basically aims to emulate this in man-made systems. From the invention of fire to space exploration, many steps have been taken by humanity to benefit itself. These include computers to help in solving complicated problems hence reducing human workload. From here, basing their arguments on the development of computers, researchers have attempted to develop an

intelligent system matching human intelligence by learning, reasoning, understanding language, and solving problems.(Ramesh et al, 2004).

The wide arrays of fields in which AI can be applied are technology, business, defence, aerospace, and health. Automation is expected to generate millions of jobs and improve various aspects of human life with increased efficiency. AI might be further delineated into physical assistants-manual, such as robots-and digital assistants, such as chatbots, that could be made available to undertake tasks that were repetitive, risky, or challenging to execute. Development of AI is an interdisciplinary field of study, integrating knowledge from mathematics, biology, philosophy, psychology, neuroscience, statistics, and computer science. It aims to develop systems that are transparent and explainable and act like an intelligent agent (Ghosh et al, 2021).

The concept of AI originally came from the Turing Test, the test designed to determine whether a machine can exhibit intelligent behaviour indistinguishable from a human's. AI has greatly changed the world and introduces a new phase of the digital revolution.(Turing et al, 1950).

## 2. Classification of AI

### 3. Classification of artificial intelligence

#### CAPABILITIES

AI capabilities refer to the underlying skill and competencies that an Ai system possesses, enabling it to perform specific types of tasks. These are more about the potential and of what an AI can achieve.

#### Functionality

AI functionality refers to the specific feature and actions that an AI system provides in practical applications. This is more about how the AI capabilities are implemented and utilized in real-world application.

### 3.1 AI in drug discovery

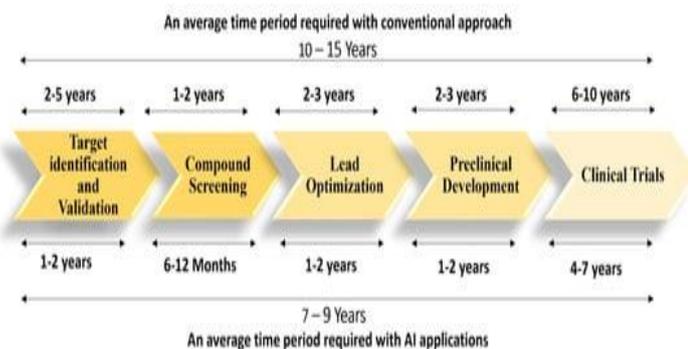
It has taken more than a few years to develop a new drug before AI and costs as much as US\$2.8 billion; further, 80-90% of the candidates fail in the clinic. As of 2022, fewer than 500 effective drug targets have been uncovered-a drop in the ocean compared

to the calculated number of druggable drug targets in humans. The early discovery stage alone is estimated to take 3-6 years, with the compound accounting for an estimated 42% of total capitalized costs in new drug development. Given the overall cost and time needed in the process of drug development, it is a little surprise that there's an increasing interest in AI-enabled small molecule drug discovery. There are numerous places in the small molecule discovery process where AI can be applied to accelerate, reduce cost, and improve success rates to enable innovation.

For instance, by applying AI models to knowledge bases of reported compounds and chemical reactions during lead identification and optimization stages, the medicinal and synthetic chemists can rapidly carry out the following operations and significantly shorten these phases:

- a).Predict/understand structure-activity relationships
- b) Make accurate ADME and toxicity predictions
- c) Accelerate synthesis planning for novel compounds/de novo design
- d) Improve route optimization for known compounds

Drug discovery and development processes are highly time-consuming, immensely expensive, and very complicated in nature.



**Fig 1: Difference in time required to discover new drug with or without the help of AI**

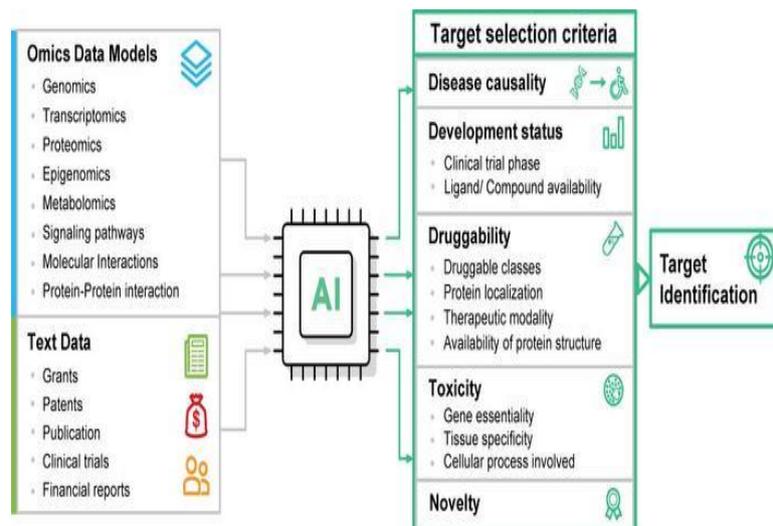
(Dhudum et al, 2024).

Drug discovery and development is a complex process that involves several key phases:

### 3.1.1 Target Identification and Validation: (Dhudum et al, 2024).

One of the most important processes in target identification is intended to reveal the biological cause of a disease and provide therapies. It involves selecting appropriate biological molecules or cellular pathways that can be altered by drugs to achieve therapeutic benefits. Biomedical data have become increasingly available in the last years, going from basic research into causes of disease up to clinical studies. However, this huge amount of data presents scalability problems regarding data analysis, integration, quality, noise, computational complexity, and interpretability, besides validation. AI can operate and analyse such complex networks of biological data. Recently, a promising method for target identification has been developed that couples multi-omics data with AI algorithms. It combined various bioinformatics and DL-based models, which were trained using disease-specific

text and multi-omics data, to carry out the prioritization of treatable genes and identification of potential therapeutic targets.



**Fig 2: method by which AI help in discovering the new drug (Belli et al, 2023).**

### 3.1.2 Compound Screening and Lead Optimization:

Compound screening is one method of testing a large library of chemical compounds for the ability to exhibit specific biological activity or induce a certain effect. That is where drug development usually comes in-the application of compound screening to look for possible new drugs or therapeutic agents. Compound screening generally means analysing each compound by testing against a target, such as proteins or enzymes, to see whether a compound provokes a certain response or blocks a specific biological process. This general concept is usually executed to come up with desired candidates for further development and optimization into effective drugs. Techniques involved in Compound Screening are: (Hughes et al, 2020).

- a) High throughput screening

- b) Focused screen
- c) Fragment screen
- d) Structural aided drug design
- e) Virtual screen
- f) Physiological screen
- g) NMR screen

This is the process of identification of small molecules interacting effectively with target proteins leading to disease conditions that have good pharmacokinetic properties and low toxicity. This is usually very long and expensive, taking approximately 10 to 12 years and estimated at US\$800 million to US\$1.8 billion per drug. The point at which AI is applied to make it easy and less expensive (Hughes et al, 2020).

**a) High-throughput virtual screening:**(Singh et al, 2024).

It is a methodology used in drug discovery where thousands of chemical compounds are being screened for biological activity. For this, AI generally used two methods:

i) Structure-based Virtual Screening: directed to find those molecules that would fit well with a target protein, predicting how well they bind together. The AI tool to be used here is Artificial Neural Networks; these can analyse protein-ligand interactions and thereby help in re-ranking the best binding poses of molecules. It has been reported to improve the prediction function by 120% more than traditional methods.

ii) Ligand-Based Virtual Screening: predicts new drugs based on compound similarities to known active compounds.

In total, SBVS pays attention to fitting and binding of the molecule to a target protein, and advanced methods are utilized such as ANNs and rescoring refinement to enhance the accuracy. LBVS, on the other hand, identifies new drug candidates by the similarity search method to known active compounds.

### 3.1.3 Preclinical study:

The preclinical stage has long been a crucial point in the drug development process, where the drug candidate underwent numerous experiments and evaluations that could yield vital information about the safety and efficacy of a drug candidate before being put into human trials. Preclinical studies aimed at collecting key information on the way the drug is dealt with in a living body and any associated risks. principal elements that constitute preclinicalresearch.

**Pharmacokinetics** (Diaconu et al, 2022).

Traditionally, the study of such aspects has included:

Animal Testing: The use of animals to predict the behavior of drugs in humans.

Clinical Trials: Drugs tested on human subjects with the aim of gaining an understanding of the drug's effects and their safety still, methods present several drawbacks, ethical, economic, and various ability among individuals. Currently, AI and Computational Models are an increasingly helpful set of tools employed to enhance these studies:

**a) Pharmacokinetic Parameter Prediction:** The algorithms of ML and DL can easily predict the absorption, distribution, metabolism, and excretion of the drug these algorithms analyze large datasets for the prediction of the behaviour of drugs and further optimization of the design of drugs.

**b) Physiologically-Based Pharmacokinetic Models:** AI would be very useful in the development and refinement of such complicated models that simulate the passage of drugs through the body, reducing animal studies and clinical trials.

**c) Drug Release and Absorption:** AI models predict the release and absorption of a drug through analysis of properties both in the drug itself and its delivery system.

**d) Drug Metabolism and Excretion:** AI helps

predict the metabolic and excretional pathway that a drug will take, including potential drug-drug interactions and enzyme interactions within the body.

In other words, AI enhances the likelihood of the accuracy and efficiency of predictions, while reducing the overall cost of and need for animal testing and helping in the design of better drugs more quickly. (Diaconu et al, 2022).

**Table 1: AI Tools used in drug discovery:** (Paul et al, 2020).

<u>SN</u>	<u>TOOLS</u>	<u>DISCRIPTION</u>	<u>LINK</u>
1	AMPL (ATOM Modelling Pipeline)	It is a fully accessible software program that enables users to create predictions for a diverse range of molecular features required for in silico drug development.	<a href="https://github.com/ATOMScience-org/AMP">https://github.com/ATOMScience-org/AMP</a>
2	DeepDTA	A deep learning-based tool to predict drug-target binding affinity using protein and drug sequences.	<a href="https://github.com/hkmztrk/DeepDTA">https://github.com/hkmztrk/DeepDTA</a>
3	DeepTox pipeline (toxicity prediction).	1) Data cleaning and quality control. 2)Chemical description 3)Model selection 4)Model evaluation 5)Ensemble predictions	<a href="https://www.bioinf.jku.at/research/DeepTox/">https://www.bioinf.jku.at/research/DeepTox/</a>
4	ODDT (Open Drug Discovery Toolkit).	The Open Drug Discovery Toolkit is freely accessible software including both developers and academics involved in computer-aided drug discovery (CADD). ODDT re-implements various cutting-edge methodologies and covers other external applications to enable the development of CADD pipelines	<a href="https://github.com/oddt/oddt">https://github.com/oddt/oddt</a>

### 3.2 Evolutionary change in personalized medicine by AI

The field of precision medicine is also rapidly evolving. Precision medicine can best be described as a health care movement entailing what the National Research Council originally termed the creation of a new taxonomy of human disease based on molecular biology, or a revolution in health care brought about by knowledge garnered from sequencing the human genome. It's a modern way of thinking about healthcare, designing treatments and strategies for specific patients using their own genetic profiles. It is considering medicine tailored to the individual through their personal genetics rather than resorting to a drug that works on a majority. This is much influenced by the great strides science has taken in interpreting our DNA and its consequences on our health. (Johnson et al, 2021).

Precision medicine now encompasses not just genetic information, but also multiple biological sources of data, such as proteins and metabolites, coupled with medical history, social issues, and environmental influences. This, if done through an integrated systems approach, may lead to a deeper understanding of diseases and their targeted treatment. We will use the term "precision medicine" for the greater research and philosophy involved in this approach, and use the term "personalized care" to describe how this affects care given to the individual. (Ziegelstein et al, 2017).

Precision medicine gives the doctor a reason to move beyond general guidelines on treatment

decisions, focusing on unique features of each person. This, in turn, allows more precise tailoring of treatments to the individual, affording better and more personalized care. It opens up new possibilities for effective treatment that otherwise could not have been possible. (Ziegelstein et al, 2017).

Benefits such as earlier detection of diseases and treatments tailored to the condition are being realized as precision medicine advances. Much of this progress is supported by new technologies to collect and analyse data. For example, integrating detailed genetic information with EHRs can enable scientists to discern new patient characteristics from real clinical data. (Johnson et al, 2021).

This confirms, improves, and aids in the diagnosis of several disease types to see whether additional treatments will be needed. One of the most documented benefits of precision medicine relates to treatment guided by genetic information.

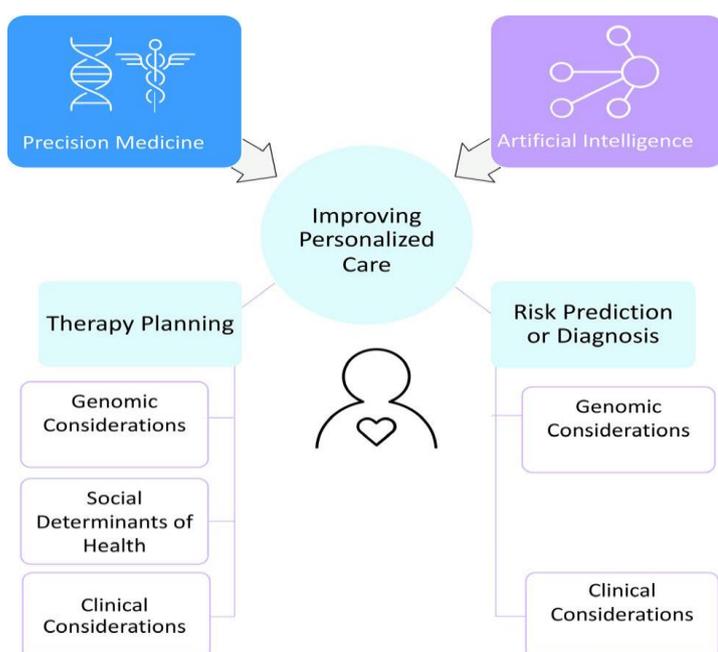
Also, there are guidelines to help the doctors to use the mentioned genetic tests and thereby allow them to improve the drug therapies. The genomic profiling of tumours helps in developing targeted treatment plans for cancers like those of the breast and lungs. All in all, precision medicine offers a path to more accurate diagnostics, prediction regarding the diseases well in advance before the symptoms become apparent and personalized treatment plans which are safer as well as effective. The results from this approach are gaining momentum worldwide, and initiatives

such as the UK Biobank, BioBank Japan, and the Australian Genomics Health Alliance further serve to illustrate the adoption of precision medicine globally. (Ziegelstein et al, 2017).

AI and precision medicine are converging to assist in solving the most complex problems in personalized care. It includes:

### 3.2.1 Therapeutic planning

### 3.2.2 Risk Prediction or Diagnosis



**Fig 3: Needs to be considered in order to implant AI in personalised medicine**

### 3.2.3 Therapeutic planning

It involves the creation of an integrated, individualized plan of treatment regarding the peculiar medical condition of a patient, including his needs and circumstances. This is therefore done in the interests of optimizing therapeutic outcomes in the care of the patient by tailoring

interventions to the peculiar profile of the patient. Patients with pharmacogenomically actionable variants may require altered prescribing or dosing. Knowing a patient's genetic constitution in advance will definitely help in tailoring medicines and dosages to individual needs, mapping their genome in advance. Genetics and scientific knowledge were integrated using AI quite early, keeping in view the complex biological insights from genes. For example, AI has already been used to predict the structure of proteins, which genes are turned on or off, and how genetic variation might affect disease and treatment. And AI holds promise for predicting patient response to various treatments. Analysing gene expression data, AI models can predict the response to treatments, thus guiding physicians in the proper direction in treatment. However, additional studies are needed to refine these models, as their predictions must be validated. Examples include the following:

a) **Medulloblastoma:** It is a type of brain tumor, in this treatment, distinct subgroups of the disease were identified through AI analysis of genetic data. This allowed doctors to tailor treatment specifically to the "wingless" subgroup with chemotherapy alone, avoiding the need for whole-brain radiation, which can have severe side effects.(Sengupta et al, 2017).

b) **Radiogenomics:** It is a new branch of science that integrates imaging with genomics for forecasting the response of patients to radiation therapy. AI has been used to analyse MRI scans for predicting genetic information that helps in

personalizing cancer treatment. Nevertheless, the main problem is that data are scarce. (Trivizakis et al, 2020).

### 3.2.4 Risk prediction or Diagnosis

Patients with genome-validated risk for disease may deserve different strategies for preventive care. For instance, in cardiovascular medicine, risk prediction, such as for heart failure has been done for a long period. Now, new approaches enable the forecasting of such risks even when patients show no symptoms. Applying these predictive models to personalized prevention strategies might reduce the incidence of heart-related diseases. AI-assisted identification of phenotype features through electronic health records (EHR) or images, along with matching those phenotype characteristics with genetic variants, may provide for the speedier diagnosis of genetic disorders

**Table 2: AI tools used in personalized medicine**

AI Tool	FUNCTION
<b>TEMPUS<sup>17</sup></b>	Tempus leverages AI to analyse clinical and molecular data, providing insights for personalized cancer treatment. It integrates genomic sequencing data with clinical records to recommend targeted therapies.
<b>IBM Watson for Genomics<sup>18</sup></b>	This platform analyzes genomic data and integrates it with clinical data to provide insights into cancer treatment options and help identify personalized therapeutic strategies.
<b>OncoKB<sup>19</sup></b>	An AI-powered knowledge base that provides information on the clinical significance of cancer mutations, aiding in the development of personalized treatment plans.

## 3.3 AI used in Cancer Diagnostic

### 3.3.1 Gastrointestinal Cancers:

AI technologies play an increasingly important role in gastrointestinal cancers, from colorectal cancer to gastric cancer. AI tools analyse patient data in order to enhance colorectal cancer screening and predict the progression of gastric cancer by testing indicators through advanced imaging techniques like Helicobacter pylori infection. While AI has enhanced the early diagnosis through blood tests and endoscopic imaging, challenges persist due to a lack of randomized controlled trials and significant limits of current predictive models. New AI algorithms, such as multi-task logistic regression and random survival forests, will be developed to bridge these gaps into more clinically relevant diagnostic and prognostic information. (Klang et al, 2023).

### 3.3.2 Lung Cancer:

AI has lately emerged as an important tool in the diagnosis of lung cancer in a manner tantamount to very early detection and screening. With deep learning and machine learning, AI processes great volumes of data in order to analyse pulmonary nodules with high precision to detect malignant changes. Other applications include segmenting tumor regions, detecting lymph node metastasis, and estimating gene mutations. The use of AI interprets low-dose CT scan images with improved diagnostic accuracy while reducing false-positive results. It is useful also in the follow-up of the temporal changes in tumor and non-tumor tissues, employing sophisticated image analyses such as convolutional and recurrent neural networks to identify benign and malignant nodules.

### 3.3.3 Breast Cancer:

AI technologies have their great advancement in diagnosis and treatment regarding breast cancer. AI-assisted MRI techniques combine the detailed quantitative and qualitative data for response prediction to treatment, whereas it deals with the assessment of breast density. It enhances the detection, segmentation, and classification of lesions in the breast to further assist in differentiating malignant conditions from benign ones. However, other challenges include that there is a need for large and good-quality data and improvement in the methods of classification. Though the development of AI tools, including Coronary artery disease systems developed by deep learning, is still in its infancy stage, these technologies hold a great promise for improving the diagnosis and treatment of breast cancer significantly in the future.

### 3.4 AI in Quality Control and Quality Assurance

Any pharmaceutical product is a delicate balance of several factors to make sure quality and consistency exist between batches. Conventionally, there are many aspects that have to be done by hand to keep it consistent and quality-checked; this can take very long and hence be prone to mistakes. This is why the integration of AI in such processes has become increasingly important (Paul et al, 2020). For example, the FDA promoted "Quality by Design" to facilitate the understanding and control of the main parameters having a significant impact on quality for a given product by the manufacturing companies; it's a

way to make the manufacturing more reliable (Rantanen et al, 2015).

In real life, AI can strongly complement this process. For instance, Gams et al. combined human expertise with AI to analyse data about production batches. They developed rules guiding future production-decisions by means of decision trees-models that support making decisions based on data. Similarly, Goh et al. applied artificial neural networks (ANNs) to check the uniformity of theophylline pellets, a sort of drug. Their AI model could predict the dissolution performance of the pellets, with an error less than 8%, hence permitting batch-to-batch consistency assurance. Real-time monitoring during the process is also possible with the help of AI. For instance, ANN-based systems can predict a future condition-such as temperature changes in freeze-drying processes-which would help in maintaining the quality of the product (Gams et al, 2014). Besides, automated tools like electronic lab notebooks and advanced data analysis techniques make quality control even better. These technologies make the handling even of complex data much easier and at the same time ensure that the final product is of high standard (Paul et al, 2020).

### 3.5 AI in nanomedicine

Nanomedicine is an emergent, rapidly evolving field with versatile drug carriers. AI can turn nanomedicine into rapid development of new nanoscale treatments that improve diagnostic tools and ensure better drug delivery. By analysing and recognizing patterns in data, AI helps develop and

optimize nanoparticles intended for targeted drug delivery, imaging, and sensing. It is able to predict how such nanoparticles would perform, including stability and effectiveness, to aid researchers in designing the particles to possess properties most suitable for a given medical application. For example, in cancer treatment, AI can optimize a combination of drugs and improve delivery systems for better treatment outcomes. Already, algorithms of deep learning have shown brilliant results in diagnosing and treating melanoma, underlining AI's potential to advance personalized medicine and revolutionize healthcare (Vora et al, 2023).

AI is enhancing the use of such tiny particles-nanocarriers-desired to ferry drugs into the body-while automating their design and testing. AI ensures that these particles are compatible with drugs, stable, and active, especially in the case of tumours. AI can predict the behaviour of these particles in simulations without running too many repetitive experiments. Constructing databases of the characteristics and safety of these particles is another activity of AI. Studies have shown that AI can reveal how nanoparticles traverse through blood vessels; this helps in designing better drug delivery mechanisms and explains why some treatments may not work as well (Dasc et al, 2022).

### 3.6 AI in Adverse drug reaction (ADR) detection

A number of AI applications in research are related to the prediction and detection of ADRs. For example, Mohsen and co-authors integrated two types of data sources: gene

expression profiles related to drug toxicity and reports of ADRs from the FDA. Further, this data was analysed with DNNs, involving steps like filtering and cleaning the data, feature selection of important ones, fine-tuning, etc. In this case, it refines the prediction of ADRs and enhances the precision of drug safety assessments.<sup>40</sup> Yalçın et al designed a machine learning tool that calculated the risk of the development of an ADR by merging the severity of the reaction with a neonatal adverse event scale and a probability algorithm. This was applied to a risk matrix analysis performed by a multidisciplinary team including a clinical pharmacist. Meanwhile, hammann et al. used decision trees, a type of machine learning, to investigate chemical, physical, and structural drug attributes potentially causing ADRs. The performance of their models was very high, reaching from 78.9% to 90.2% for allergic, kidney, CNS, and liver reactions (Yalcin et al, 2022).

## 4. Challenges and solution

### 4.1 Bias and Fairness (Abramoff et al, 2023).

Health AI can reflect and amplify biases in their training data, which results in huge disparities in patient care. For example, an AI model trained on data of only one demographic ethnic or socio-economic background will not generalize well for other populations. This may lead to underrepresented groups receiving misdiagnosis and inappropriate treatments.

**Solution:** Ending bias in AI involves the following strategic steps: First, that the training data are

diverse and representative of the various demographics within view: enough people of ethnic, age-related, gender-based, and socio-economic groups, for instance. Second, algorithms need to be developed that can detect and reduce bias, too. Regular audits and evaluations of AI systems enable identification of potential disparities for alteration. Looking at all these, from engaging the professionals to patients, involving their advocacy groups to get a better understanding of what is needed to determine fair practice, it really enlightens. Doing that can let us develop AI providing unbiased and accurate care for every patient.

#### 4.2 Data Privacy and Security (Arhud et al 2021).

Another most important challenge with AI-driven healthcare involves the need to ensure privacy and security for patient data. For effectiveness, AI systems require broad and sensitive patient information; this, however, includes some key risks of data breaches and unauthorized access. Protection of this data involves stringent security measures, like encryption, that render it unreadable to any person not authorized to see it.

**Solution:** The best way to underpin the basic issues related to personal data privacy and security with the help of AI based health care systems has been given below: First, patient data should be strongly encrypted when stored. Data must be kept in a format entirely uninterpretable to unauthorized personnel. It includes changing sensitive information into a secured form so that only authenticated users can access the same.

Similarly, safe storage is essential to prevent data from physical and digital theft and destruction. For this reason, access controls should be implemented with the purpose of ensuring no unauthorized person can access or control the data. Compliance with privacy regulations, such as General Data Protection Regulation, or the Health Insurance Portability and Accountability Act, should be promulgated to set the foundation on how the information shall be maintained and protected. Regular security audits and updates to the AI systems help them detect potential loopholes and keep the data protection up to date. Training of health staff for data privacy and security practices enables them to know why patient information needs to be protected. These focused means would ensure that AI-based healthcare is responsibly and securely handling patient data without eroding public trust.

#### 4.3 Cost and Resource Allocation (Khanna et al, 2022).

Using AI in pharmacy presents many challenges, especially to small health systems with scarce resources. AI systems will be costly at the outset: one incurs both costs of software purchase or development and hardware infrastructure. Secondary expenses on recurring basis increase the cost further through maintenance, updating, and technical services. The most complex computing systems and adequate data storage are required for AI installation and add to the cost in general. The cost also entails training human personnel to appropriately utilize AI systems. This is specialized training for pharmacists and other

health professionals on how to interpret properly AI recommendations. It's time and resource-intensive; it takes away from other types of pharmacy practice activities. AI introduction can also affect workflows and productivity. Although AI will increase the efficiency and patient services of the pharmacies, there will be an adjustment period during which productivity may temporarily fall, especially for the scarce resources in the smaller pharmacies. It is also economic; the value obtained through the use of AI tools, despite their roles in medication management and elimination of errors, takes a long time to be realized at the investment level. This creates a challenge in the implementation of AI in pharmacy given this uncertainty poised against a need for justification of an expense in a strained budgetary environment.

#### **Solution Phased Implementation:**

The implementation of AI systems on a basis of a phased approach helps pharmacies cope more adequately with the costs involved. In addition to full-scale deployment, starting with a pilot program enables an assessment of the value of the technology and adjustment in implementation strategy according to real-world feedback. This gradual integration spreads out the main costs over time and enables a more manageable financial commitment (Khanna et al, 2022).

#### **Partnership sand Collaborations**

Accordingly, pharmacists may consider strategic partnerships with technology companies, academia, or research institutions to have an

immediate access to AI tools and expertise at a much lower cost than having them exclusively developed. The partnerships may be based on mutually agreed funding, joint research, or preferential pricing for software and training (Khanna et al, 2022).

#### **4.4 Workflow Integration:**

Introduction of AI into a pharmacy routine may change its practice pattern. An AI tool utilised for the purpose of drug interaction checks at a pharmacy should be incorporated into the prevailing procedures at that particular pharmacy. It should make the work easier and not disturb the workflow of the working staff.<sup>30</sup>

Solution: The pharmacies will need to work in workflow changes and train their staff in the appropriate utilization of the new technology without creating additional steps or confusion (Karalis et al, 2024).

#### **4.5 AI Regulatory and Ethical Issues in Pharmacy:**

The inclusion of AI in pharmacy exposes issues much more than any technical barrier; rather, it raises significant regulatory and ethical questions that require copious attention. Compliance with the existing health regulations, particularly those of the US FDA and the European Medicines Agency (EMA), is important in ensuring safety, effectiveness, and reliability before clinical use of AI systems. For example, AI tools used in administering drugs or making diagnoses should undergo stringent testing to ensure that they do not undermine patient safety;

failing to adhere to them may lead to serious lawsuits and health consequences. The other sensitive dimension is related to the ethical use of patients' consent and transparency. How the data collected will be used in training the AI to carry out analytics must be known and understood by the patients so that they can give their consent to such usages. Transparency about the decision-making processes of AI tools is needed. Patients and healthcare providers should understand what is informing the AI recommendations, limitations, and possible risks for truly informed decisions.<sup>31</sup>

**Solution:** several proactive strategies can be employed. The compliance with regulations would include adherence to standards laid down by regulatory bodies such as FDA or EMA. It would mean that AI developers and pharmacy practitioners must be fully engaged in the validation of the AI tool-by testing for safety, efficacy, and reliability of the AI tool before its deployment. Updates are also needed on a regular basis, continuous monitoring of deployed systems for compliance with evolving regulations and standards (Kuwaiti et al, 2023).

#### 4.6 Accuracy and Reliability (Vo et al, 2022).

Precision and reliability of the AI system in pharmacy is an essential element of patient safety in treating outcomes. These algorithms employed by AI systems rely on a vast repository of data relating to drug interactions, dosages, or even possible duplicate prescriptions to make decisions at the right time. At the end of the day, however, it is the quality of that data and the completeness with which those inputs are used, which is being

harnessed to train the algorithm. More miserable or outdated data can lead to defective decision making-a hazardous outcome, perhaps as a missed deadly drug interaction. Its applicability is also challenged on basis of the trustworthiness of its tools, their skills in dealing with variability and complexity in the real practical situation. Training an AI system on a small dataset may put it into a state of distrust in situations where it hasn't been trained for, this shall put biases and inaccuracy, especially if the AI performs actions skewed towards one demographical category, this would lead to incongruence of the treatment recommendations. It should maintain such data strong and current so as not to reduce the effectiveness of AI in pharmacy practice.

**Solution:** It includes rigorous validation of the AI systems, extensive testing in various clinical settings to establish the performance of AI with accuracy for diverse scenarios and patient populations, and regular updates of AI algorithms and datasets to integrate new medical knowledge and to tackle certain deficiencies. More exciting is the realization that embedding human oversight within AI's decision-making facilitates error detection and correction that, otherwise, might be left undetected by the AI system. Active review of AI recommendations by a pharmacist or healthcare provider, using their clinical judgment to make final decisions, must be maintained as a matter of course so that technology enhances, rather than replaces, human expertise.

#### 4.7 AI Training and Expertise in Pharmacy (Wubineh et al, 2024).

AI in the pharmacy requires specialized training and expertise at high levels, so both the technology and those using it can work well. Training in AI provides the pharmacy personnel with the knowledge and skills needed to effectively use and interpret AI tools, which is relatively complex. This means that pharmacists and technicians must be trained not only in the operation of AI systems but also in the integration of AI-generated insights into daily workflows. In this regard, training on the use of AI tools in general would involve comprehension of their underpinning algorithms, their strengths, and limitations, as well as problem-solving when issues occur. While the training programs effectively should be inclined towards practical aspects, such as how to input data on AI systems and understand the results, other aspects also go a long way, in theory-for instance, the principles of machine learning, data analysis.

**Solution: Detailed Training Programs:** The designing and implementation of detailed training programs shall be necessitated. In fact, the programs should range from operational use to the theoretical basis of the AI tools. Once more, the training shall involve practical sessions of the use of AI systems, with understanding outputs and integration into day-to-day workflows. Furthermore, the educational modules must describe the algorithms and data management practices behind the recommendations proposed by AI so that staff can have an idea about how AI

comes up with recommendations. Hands-on training can be inculcated with case studies and real-life scenarios useful for the proficiency of using the AI technology for pharmacists and technicians.

#### **Collaboration with AI Developers:**

Greater collaboration between the pharmacies and developers of AI will offer better training and support. For instance, AI developers can deliver specialized training sessions, specific resources, and an understanding regarding the technology's capability and limitations. The collaboration supports the accuracy of training materials relevance and staffs gets direct support from the ones who understand the intricacies of the AI systems.

### 5. Pharmaceutical industry and AI

#### 5.1 Example 1:

Many companies were under stress to find the best drug within the shortest period. Possible due to the SARS-CoV-2 viral epidemic. Besides, for such decisions, some companies have inclined towards the use of AI with the combination of prevailing data. Some examples of those businesses that, through their efforts, could find workable solutions in order to fight the COVID-19 virus. AI has proceeded with giant leaps on its own in research related to COVID-19: tracing the virus, accelerating the development of new drugs and vaccines, and meeting global health challenges. In spite of the very high toll in case numbers and deaths due to COVID-19, there remains a dire need for effective treatments and

vaccines. AI has furthered drug discovery by analysis of big datasets to identify promising compounds. New molecules are being discovered and existing ones optimized using both ligand-based and structure-based AI technologies. New drugs using AI are yet to enter clinical trials, but repurposing of drugs identified by AI is already in clinical testing. The pandemic accelerated the use of AI in drug development, thus positioning AI as a crucial tool in combating COVID-19 and other diseases in the future (Floresta et al, 2022).

### 5.2 Example 2:

**Table 3: Collaboration of AI and Pharmaceutical Company** (Dashpute et al, 2023).

Sr. No.	Pharmaceutical Company	AI Company	Purpose
1	Pfizer	IBM Watson XtalPi Concerto Health AI Catalia Health	Drug Discovery Drug accuracy & Efficacy Real world data in Oncology Increase patient clinical Journeys
2	Novartis	Google Deepmind	Clinical trial: optimize patient selection, treatment and protocol during clinical trial
3	Johnson & Johnson	Exscientia	High-throughput screening: to identify potential drug leads
4	Merk	Berg Health	Biomarker Research: To identify and validate biomarkers that aid disease
5	Bayer	Atomwise	Transform using small

			drug discovery
6	Sanofi	ORKIN	Used to stratify patient groups to provide more targeted and effective therapies
7	AstraZeneca	Benevolent AI	To find potential novel medication for chronic disease
8	Abbvie	Aicure	To enhance adherence in schizophrenia trial
9	GSK	Insilico Medicine	Drug design and optimization
10	Roche	Benevolent AI	Drug Development

### 5.3 Example 3:

**Table 4: AI-derived drugs in clinical trials**

Sr. No.	Company	Indication	Compound	Trial number
1	BenevolentAI	Atopic dermatitis	BEN-2293	NCT04737304
2	Exscientia	Solid tumors Obsessive compulsive Disorder Alzheimer's disease Psychosis Inflammatory diseases	EXS-21546 DSP-1181 DSP-0038 EXS4318	NCT04727138 Undisclosed Undisclosed Undisclosed
3	Insilico Medicine	COVID-19	ISM3312	CTR20230768
4	Nimbus Therapeutics	Nonalcoholic steatohepatitis	NDI-010976/GS-0976	NCT02856555,

5	Pharos iBio	Acute myeloid leukemia Ovarian cancer	PHI-101	NCT04842370 NCT04678102
6	Recursion Pharmaceuticals	Cerebral cavernous malformation	REC-994	NCT05085561
7	Relay Therapeutics	Solid tumors	RLY-1971/RG-6433	NCT04252339
8	Schrödinger	Non-Hodgkin's lymphoma	SGR-1505	NCT05544019
9	Structure Therapeutics	Type 2 diabetes Obesity	GSBR-1290	NCT05762471
10	Valo Health	Post-myocardial infarction Acute kidney injury	OPL-0301	NCT05327855

### CONCLUSION:

In all, AI has marked a new era in the history of many industries, including health and pharmacy. Extensive investigation into AI, from historical support to advanced applications, carries on an aspiring assertion of this technology: improving drug discovery, personalizing medicine, and offering better patient care. More importantly, the integration of AI systems accelerated the rate of research and development while opening more avenues for dealing with complex medical challenges, including the identification and treatment of diseases like cancer, diabetes. But with this development come other challenges that

concern data bias, privacy, and strong regulatory frameworks. Response to these challenges is necessary in a way that ensures the benefits of AI are realized but this does not compromise ethical principles or patient safety. The future of health that includes AI requires researchers, practitioners, and policy thinkers to work together. The focus, if we are ever going to elicit the true potential of AI, will have to be on transparency, training, and holistic methodologies. As we sit on the edge of this new age in pharmacy and medicine, our commitment should remain firm toward making a truly responsible and inclusive environment where the technology actually serves the needs of humanity's health.

### CONFLICT OF INTEREST:

The author declares no conflict of interest.

### ACKNOWLEDGEMENT:

We would like to express their sincere gratitude to A. R. College of Pharmacy & G. H. Patel Institute of Pharmacy for providing the necessary facilities and support to carry out this review work. We also acknowledge the contributions of colleagues and experts in the field whose valuable insights and suggestions have enhanced the quality of this article.

### REFERENCES :

- 1) Ramesh, A. N., Kambhampati, C., Monson, J. R. T., & Drew, P. J. (2004). Artificial intelligence in medicine. *Annals of the Royal College of Surgeons of England*, 86(5), 334–338.
- 2) Ghosh, M., & Arunachalam, T. (2021). Introduction to artificial intelligence. In

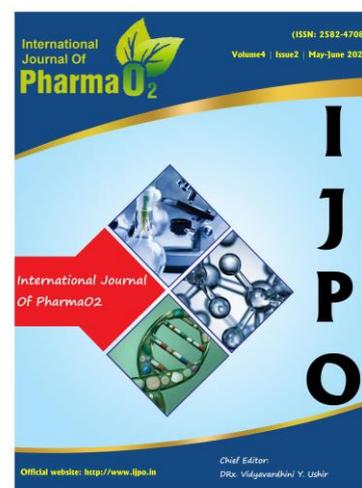
- Artificial intelligence for information management: A healthcare perspective* (pp. 23–44).
- 3) Turing, A. M. (1950). Computing machinery and intelligence. *Mind*, New Series, 59(236), 433–460.
  - 4) AI in small molecule drug discovery
  - 5) Rushikesh Dhudum , Ankit Ganeshpurkar, Atmaram Pawa, “Revolutionizing Drug Discovery: A Comprehensive Review of AI Applications” Applications. *Drugs Drug Candidates* 2024, 3, 148–171.
  - 6) Belli, B. (2023). AI drives new era of target identification and drug design. *Insilico Medicine*.
  - 7) Hughes, J. P., Rees, S., Kalindjian, S. B., & Philpott, K. L. (2020). Principles of early drug discovery. *British Journal of Pharmacology*.
  - 8) Singh, S., Gupta, H., Sharma, P., & Sahi, S. (2024). Advances in artificial intelligence (AI)-assisted approaches in drug screening. *Artificial Intelligence in Chemistry*, 2, 100039.
  - 9) Diaconu, A., Cojocaru, F. D., Gardikiotis, I., & Agrigoroaie, L. (2022). Expanding the power of artificial intelligence in preclinical research: An overview. *IOP Conference Series: Materials Science and Engineering*, 1254(1), 012036.
  - 10) Paul, D., Sanap, G., Shenoy, S., Kalyane, D., Kalia, K., & Tekade, R. K. (2020). Artificial intelligence in drug discovery and development. *National Institute of Pharmaceutical Education and Research-Ahmedabad*.
  - 11) Johnson, K. B., Wei, W.-Q., Weeraratne, D., Frisse, M. E., Misulis, K., Rhee, K., Zhao, J., & Snowdon, J. L. (2021). Precision medicine, AI, and the future of personalized health care. *Clinical and Translational Science*, 14(1), 86–93.
  - 12) Ziegelstein, R. C. (2017). Personomics and precision medicine. *Transactions of the American Clinical and Climatological Association*, 128, 140–151
  - 13) Soma Sengupta, Daniel Pomeranz Krummel, Scott Pomeroy.(2017). "Advancements in Personalized Medicine for Medulloblastoma Therapy." F1000Research.
  - 14) Eleftherios Trivizakis, Georgios Z. et.al, (2020). and Kostas Marias authored the paper titled "Artificial Intelligence Radiogenomics for Advancing Precision and Effectiveness in Oncologic Care," published in *International Journal of Oncology*, Volume 57, pages 43-53.
  - 15) Eyal Klang, Ali Soroush, Girish N. Nadkarni, Kassem Sharif, Adi Lahat.(2023). "Deep Learning and Gastric Cancer: A Systematic Review of AI-Assisted Endoscopy." *Diagnostics*, vol. 13, no. 24, article 3613.
  - 16) Filippo Lococo, Galal Ghaly, Marco Chiappetta, Sara Flamini, Jessica Evangelista, et.al "Implementation of Artificial Intelligence in Personalized Prognostic Assessment of Lung Cancer: A Narrative Review."
  - 17) **Tempus**  
<https://www.tempus.com/?srsltid=AfmBOopTxzQG-bjuJktjFII1noyP2VYjCUYBXc543ZuRzX-tf1SSF18>.
  - 18) **IBM.** "Watson for Genomics."  
<https://www.ibm.com/mysupport/s/topic/0TO500000002ParGAE/watson-for-genomics?language=th>.  
20/10/24

- 19) OncoKB. "Homepage.". <https://www.oncokb.org/>. 20/10/24
- 20) Rantanen, J., & Khinast, J. (2015) 'The Future of Pharmaceutical Manufacturing Sciences', *Journal of Pharmaceutical Sciences*, 104(11), 2715-2722.
- 21) Gams, M., Horvat, M., Ožek, M., et al. (2014) 'Integrating artificial and human intelligence into the tablet production process', *AAPS PharmSciTech*, 15(6), 1622-1632.
- 22) Vora, L. K., Gholap, A. D., Jetha, K., Thakur, R. R. S., Solanki, H. K., & Chavda, V. P. (2023). Artificial intelligence in pharmaceutical technology and drug delivery design. *Pharmaceutics*, 15(7), 1916.
- 23) Dasc, K. P., & Chandra, J. (2022) 'Nanoparticles and convergence of artificial intelligence for targeted drug delivery for cancer therapy: Current progress and challenges', *Frontiers in Medical Technology*, vol.-ii,78-80.
- 24) Chalasani, S. H., Syed, J., Ramesh, M., Patil, V., & Pramod Kumar, T. M. (2023). Artificial intelligence in the field of pharmacy practice: A literature review. *Exploratory Research in Clinical and Social Pharmacy*.
- 25) Yalçın, N. (2022). An artificial intelligence approach to support detection of neonatal adverse drug reactions based on severity and probability scores: A new risk score as a web-tool. *Children*, 9(12), 1826.
- 26) Gholap, A. D., Uddin, M. J., Faiyazuddin, M., Omri, A., Gowri, S., & Khalid, M. (2024). Advances in artificial intelligence for drug delivery and development: A comprehensive review. *Computers in Biology and Medicine*, 178.
- 27) Abràmoff, M. D., Tarver, M. E., Loyo-Berrios, N., Trujillo, S., Char, D., Obermeyer, Z., & Eydelman, M. B. (2023). Considerations for addressing bias in artificial intelligence for health equity. *NPJ Digital Medicine*, 6, 170.
- 28) Arhud, D. D., & Zokaei, S. (2021). Ethical issues of artificial intelligence in medicine and healthcare. *Iranian Journal of Public Health*, 50(11), i-v.
- 29) Khanna, N. N., Maindarkar, M. A., Viswanathan, V., Fernandes, J. E., Paul, et.al. (2022). Economics of artificial intelligence in healthcare: Diagnosis vs. treatment. *Healthcare (Basel)*, 10(12), 2493.
- 30) Karalis, V. D. (2024). The integration of artificial intelligence into clinical practice. *Applied Biosciences*, 3(1), 14-44.
- 31) Al Kuwaiti, A., Nazer, K., Al-Reedy, A., Al-Shehri, S., Al-Muhanna, A., Subbarayalu, A. V., Al Muhanna, D, & Al-Muhanna, F. A. (2023). A review of the role of artificial intelligence in healthcare. *Journal of Personalized Medicine*, 13(6), 951.
- 32) Vo, T. H., Nguyen, N. T. K., Kha, Q. H., & Le, N. Q. K. (2022). On the road to explainable AI in drug-drug interactions prediction: A systematic review. *Computational Structure Biotechnology Journal*, 20, 2112–2123.
- 33) Wubineh, B. Z., Deriba, F. G., & Woldeyohannis, M. M. (2024). Exploring the opportunities and challenges of implementing artificial intelligence in healthcare: A systematic literature review. *Urologic Oncology: Seminars and Original Investigations*, 42(3), 48-56.

34) Floresta, G., Zagni, C., Gentile, D., Patamia, V., & Rescifina, A. (2022). Artificial intelligence technologies for COVID-19 de novo drug design. *International Journal of Molecular Sciences*, 23(6), 3261.

35) Dashpute, S. V., Pansare, J. J., Deore, Y. K., & Pansare, M. J. (2023). Artificial intelligence and machine learning in the pharmaceutical industry. *International Journal of Pharmacy and Pharmaceutical Research*, 28(2), 111-131.

36) Pun, F. W., Ozerov, I. V., & Zhavoronkov, A. (n.d.). AI-powered therapeutic target discovery. *Trends in Pharmacological Sciences*



**IJPO is**

- Peer reviewed
- Bi-monthly
- Rapid publication
- Submit your next manuscript at [journalpharma02@gmail.com](mailto:journalpharma02@gmail.com)