Journal of Population Therapeutics & Clinical Pharmacology

REVIEW ARTICLE
DOI: 10.53555/jptcp.v30i18.3041

ARTIFICIAL INTELLIGENCE IMPACT ON HEALTHCARE: ADVANCED DRUG DISCOVERY AND BEYOND

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Abstract
Artificial Intelligence is the advance of human technology which can work as human brain with the help of prefeed data, AI can take the decision and implement by their own. With the help of AI car can be drive without driver in recent time, this can be done with the help of data about the driving of car is installed in the system of car with the sensors. Recently AI is used in pharmaceutical industry more frequently. In this review we discussed about types of AI and how AI can be used in the process of drug discovery and development. The use of AI in recent pandemic i.e., Covid 19 treatment and its diagnosis from various tools explained. Diagnosis of life-threatening disease like cancer can be done with the help of Machine Learning tools like CNN which show a proper image based on input data. Artificial intelligence plays crucial role in personalized medicine which uses patient's genetic profile to decide for prevention, diagnosis, and treatment of disease. The algorithm of Machine Learning which is a sub-field of AI is very useful in clinical trial which can predict a toxicity of a compound and can select the accurate candidate for clinical trial. Recently researchers using AI to predict the bioavailability of a compound and can making the prediction that how the compound will interact with proteins which will be beneficial and can reduce the cost of discovery of compound.

Keywords: Artificial Intelligence, Machine Learning, Artificial Neural Network, Convolutional Neural Network.

1. Introduction

The study of problem-solving via symbolic programming is what is known as artificial intelligence (AI), a subfield of computer science. It has significantly developed into a discipline of problem-solving with widespread applications in business, medicine, and engineering.[1] It refers to a computers or a robotic computer-enabled system's capacity to analyse the provided data and procedure outputs in a way that is comparable to how humans learn, make decisions, and solve issues.[2] Because artificial intelligence has the capacity to examine vast amounts of data and a variety of modalities, there are opportunities for it to be further investigated in the field of pharmaceutical and healthcare research.[3]
The application of artificial intelligence in the pharmaceutical and biotech industries has revolutionized how scientists produce new pharmaceuticals, treat diseases, and more during the last seven years.[4]

Drug development is an extremely expensive, time-consuming, and formalized process in the pharmaceutical industry. The different stages of drug development typically cost between $1 and $2 billion and take up to 15 years to complete. [2] Making a drug development process more efficient would lower costs, speed up development, and raise the likelihood of success. This is evident from both a patient and corporate perspective.[4]

The COVID-19 pandemic made it abundantly evident that cutting-edge and new technologies are needed to respond to the emergency and address the problems caused by the underdeveloped healthcare infrastructure and financial load.[5] The identification and validation of chemical compounds, target identification, peptide synthesis, assessment of drug toxicity and physiochemical properties, drug monitoring, evaluation of drug efficacy and effectiveness, and drug repositioning are all made possible by computational modelling based on Artificial Intelligence and Machine learning principles.[6] Neural network models and deep learning are being used in machine learning to discover clinically important aspects in imaging data at an early stage, especially in cancer-related diagnosis.[7]

Artificial intelligence is used to identify the proper excipients, decide on the development process, and make sure the specification is met throughout the process in accordance with compliance. Pharmaceutical product development uses model's expert systems, artificial neural networks, etc. AI is used in manufacturing to impose limits on manufacturing faults through automated personalized production.[3]

It is possible to swiftly predict many novel compounds for different biological end points using current computer models, such as those built on quantitative structure-activity relationship (QSAR) techniques. The current models, such as those used in commercial drug discovery tools, can predict basic physiochemical characteristics, such as solubility and log P, and are thus quite accurate at predicting the pharmacokinetic characteristics of novel compounds with basic mechanisms.[8]

2. Types of Artificial intelligence

2.1 AI type 1

2.1.1 Narrow AI

Narrow AI is the most common type of AI which can carry out a specific task. Although it develops to performs one task at a time, its capabilities are confined to that one.[9] This type of AI is helpful in controlling and maintaining traffic signal, recognition of face, playing chess etc. It consists of an IBM chess algorithm that can predict moves and identify the chess pieces on the chessboard. Because it lacks a memory system, it is unable to use prior information. Virtual assistants like Alexa, Siri, and Google Assistant are the example of narrow AI.[10] Even the most highly trained humans struggle to understand and analyse massive data sets as quickly, accurately, and efficiently as narrow AI systems can. This makes them effective tools for accelerating the drug development process.[11]

2.1.2 General AI

A sort of intelligence known as general artificial intelligence (GAI) can complete any intellectual work effectively and on par with a human.[9] The mechanisms of general artificial intelligence can change in response to various surroundings and circumstances. Self-driving cars are the example of general AI.

For the development of general AI, researchers needed a machine with human-level intelligence. Theoretically, an AGI system might read, understand, and enhance code written by humans.[12] Since broad general AI systems are still a developing field, creating such systems will need a lot of work and time.

2.1.3 Super AI

It is an imagined version of artificial intelligence that is not yet attainable. In addition to being able to learn and adapt at a rate that is significantly faster than human intellect, super AI would be able to solve complicated issues that are beyond the scope of human capacity.[9] Super AI has been questioned for its existential hazards, yet its potential for revolutionising pharmaceutical industry makes it seem like a highly positive development.[10]

2.2 AI type 2

2.2.1 Reactive machines

Reactive machines can respond to current conditions; they cannot remember the past or use it to inform the judgments they make today.[13] Reactive machines include IBM's Deep Blue system and Google’s Alpha Go.[9] They can only perform the exact duties for which they were created, and they are readily mislead.[14]

2.2.2 Limited memory

Past experiences or certain data can be temporarily stored by machines with limited memory.[9] Limited memory AI can see into the past and track certain objects or circumstances across time, in contrast to reactive machines. However, due to memory constraints, this information is not retained in the AI's memory for it to learn from, the way humans may interpret their achievements and mistakes.[15]

2.2.3 Theory of mind

Theory of mind AI ought to have human-like social skills and an understanding of human emotions, personalities, and opinions.[9] To assess a person’s emotional state more precisely, researchers have created a skeletal recognition programme to measure the angular velocity of limb motions. An AI bot that exhibits empathy can anticipate the needs and behaviours of users or other people in their surroundings. This forecast is crucial in several industries, including healthcare, marketing and advertising, education, and customer service.[16]

2.2.4 Self-awareness

Self-awareness Artificial intelligence is the way of the future. Super intelligent and endowed with their own conscience, feelings, and self-awareness, these artificial beings will be.[9] The distinction between self-awareness and consciousness must be made, as the former entails recognising that awareness, whilst the latter refers to being aware of one's own environment and body.[17]

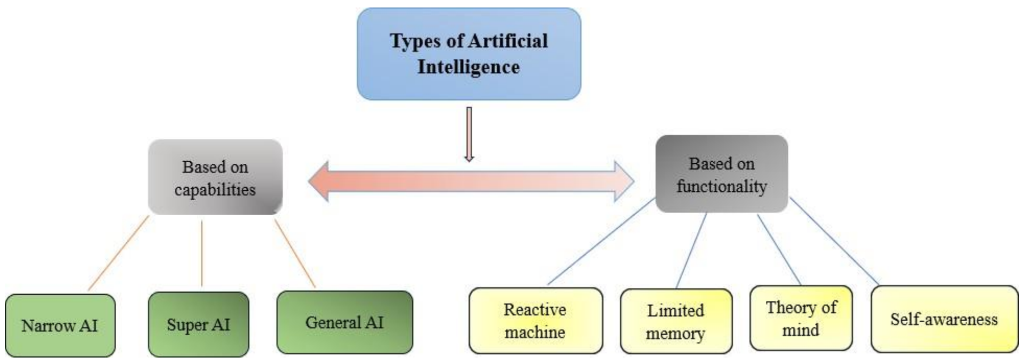

Fig. 1: Types of Artificial Intelligence

3. Machine learning in AI

Machine learning is a subfield of Artificial intelligence, it uses statistical techniques and has the capacity to learn either explicitly or without being programmed. Supervised, unsupervised, and reinforcement learning are the three categories for machine learning.[8]

By significantly advancing several R&D fields, artificial intelligence and machine learning techniques have the potential to raise the likelihood of developing drugs success.[1] Classification and regression techniques are part of supervised learning, and the prediction model is built using information from input and output sources.

Disease diagnosis is included in the output of supervised machine learning. Subgroup identification, drug effectiveness, and ADMET prediction while using subgroup regression.[8]

While k-clustering and principal component analysis are instances of unsupervised learning methods.[18] Making decisions in a specific setting and carrying those decisions out to maximize performance are key drivers of reinforcement learning. The results of this kind of ML include experimental drug design in decision-making and de novo drug design in execution, where both can be accomplished through Quantum chemistry and modelling.[19]

To provide people new insights, machine learning (ML) develops a distinctive algorithm—not a specific algorithm—that focuses on the aspects of the data and turns them into knowledge that computers can interpret.

There are several common algorithms from which researchers might select. Artificial neural networks (ANNs) with several layers of nonlinear processing units are used in the class of machine learning techniques known as deep learning (DL) to learn data representations.[9]

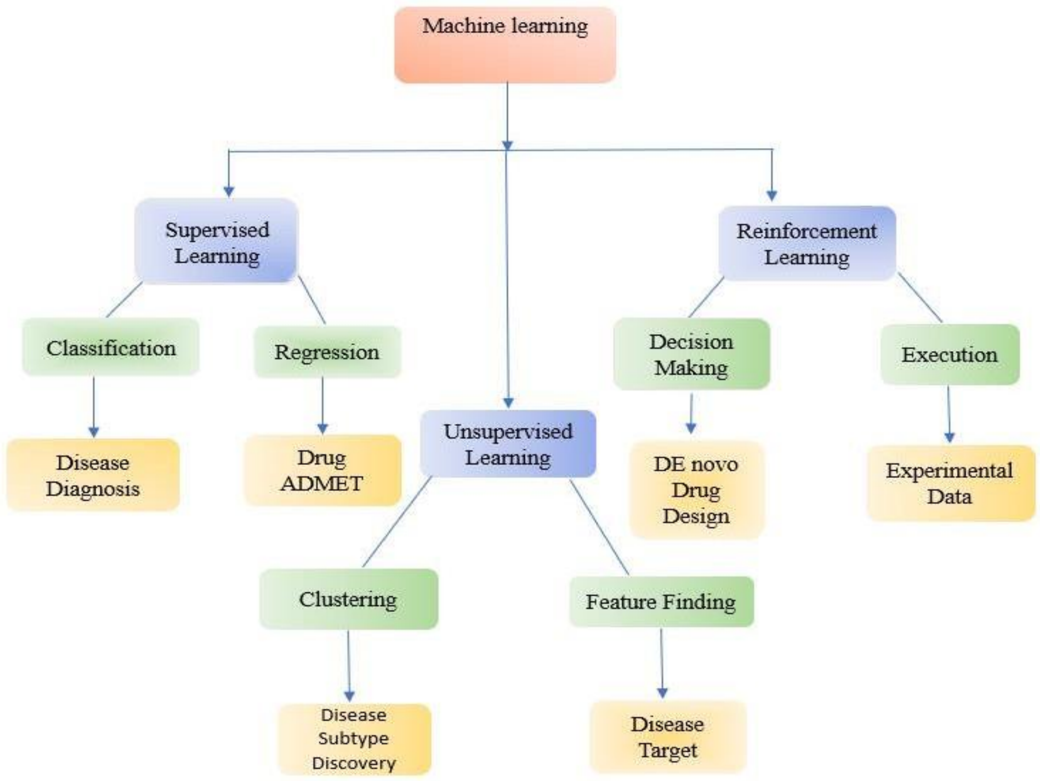

Fig. 2: Brief overview of machine learning

4. Drug discovery using AI

Due to a lack of adequate technology, it is more difficult to create many therapeutic molecules from a chemical space. This situation may be improved by applying AI in the drug development process.[20]

Drug discovery and biotechnology depend heavily on the simulation of bio-molecule structures using intricate, physics-based atomic techniques like molecular dynamics (MD).[21] Without the need for additional experimental research, the analysis of a well-curated 3D structure frequently gives direct insights into biological and biochemical activity.[22]

The one-dimensional (1D) string of amino acids that makes up a protein's three-dimensional (3D) structure determines how that protein functions biologically. In order to comprehend how proteins function biologically and to find new treatments that can either activate or inhibit proteins to cure certain disorders, knowledge of protein structures is employed.

Given the information gap between a protein's 1D amino acid sequence and its 3D structure, it is significant to create algorithms that can predict 3D protein structures in order to aid in the development of novel drugs and the comprehension of protein-folding disorders.[21] The discovery of drug with the help of AI can be done using simulation experiments to search through millions of chemical compounds in various databases for prospective medications, and the second is to find novel drugs that can bind to the targets and lessen their infectiousness.

The emergence of epidemics and pandemics like Covid-19 and influenza, as well as the prevalence of serious illnesses like cancer and heart disease, show the continued need for drugs discovery that can be done with the help of AI. In order to mine the data and identify the enzyme, researchers from Imperial College London and the AI drug discovery business BenevolentAI used internally built algorithms. Targeting adaptor-associated protein kinase 1 (AAK1) as a potential target against COVID-19.[23]

4.1 Target identification in drug discovery

One of the most important processes in the drug development process is target identification, which helps to determine the biological cause of disease and create effective treatments.[24] Language Models with AI capabilities help speed up target recognition and enhance research. The use of automatic biomedical named entity recognition (BioNER) is a useful method for revealing the connections between substances, genes, targets, and illnesses.

Synthetic data are data that have been manufactured intentionally to resemble real-world patterns and traits. Synthetic data may be produced to model different biological circumstances using AI algorithms, allowing researchers to investigate and examine a wider variety of possibilities.[25]

4.2 Virtual screening of compounds

Artificial intelligence (AI) may be used to digitally evaluate and improve substances, determine their bioactivities, and identify protein-drug interactions. The establishment of prediction models that can spot substances with a high likelihood of binding to a target protein is one method AI may aid with virtual screening. Various forms of data, including known protein-ligand complexes, structural details, and molecular descriptors, can be used to train these models.

When developing a new drug, it is important to take into account the physico-chemical characteristics of the compound, including ionisation level, intrinsic permeability, solubility, and partition coefficient (logP), since these may indirectly affect how the compound interacts with a target receptor family.[26]

In addition to being utilized for virtual screening based on synthesis feasibility, algorithms like Nearest-Neighbour classifiers, RF, extreme learning machines, SVMs, and deep neural networks (DNNs) may also forecast in vivo activity and toxicity.[27]

4.3 Drug target interaction

Understanding a drug's interactions with a receptor or target is crucial for understanding its efficacy and utility. Drug repurposing research has recently focused a lot of attention on drug-protein interactions. Due to the abundance of available drugs and target information in enormous datasets, ML algorithms have emerged as the cutting-edge method for estimating drug-target interactions.[5]

Occasionally, it is also conceivable that produced drug molecules interact with proteins or receptors that were not planned, causing toxicity. As a result, it is essential to estimate drug-target interactions using drug target binding affinity (DTBA). By considering either the characteristics or similarities of the drug and its target, AI-based approaches may estimate a medication's binding affinity.

The target and drug's chemical components are considered while determining the characteristic vectors using aspect-based interactions. As opposed to similarity-based interaction, which consider how similar a drug and target are to one another, similarity-based interaction assumes that comparable pharmaceuticals will interact with similar targets.[28]

4.3 Prediction of toxicity

Premarketing drug safety has been demonstrated to benefit greatly from the use of AI approaches, particularly in the field of toxicity assessment. A crucial phase in the medication design process is determining the effects of compounds on humans, plants, animals, and the environment.[29] Various computational, in silico methods have proven useful in predicting drug candidate toxicity. Target-based predictions and quantitative structure-activity relationships (QSARs) are two methods that evaluate numerous pharmacological characteristics to predict toxicity.[30]

5. Personalized medicine

Some people get certain diseases, including cancer, while others do not. These medical conditions might have genetic causes and other varying variables including age and lifestyle. Because of this, thinks that medicine should treat each patient's ailment individually as distinct, with medicine catered to the person's past as well as biology. This strategy for doing medical practice is referred to as Precision or Personalized Medicine.[31]

The predictability of drug-target disease-treatment pharmacology outcomes have significantly increased due to a novel approach using AI-integrated mechanistic models and historical and current patient electronic health records, along with preclinical and clinical systems biology "bigdata."[32] Genetic data, which is a component of the baseline data used to personalize or otherwise customize medical therapy or administration, is utilized to aid with this.[33]

The advancement of medical AI has made it easier for physicians to resolve challenging clinical issues. Healthcare personnel may use systems like ANNs, evolutionary computation, fuzzy expert systems, and hybrid intelligent systems to help them manage data. The biological nervous system serves as the foundation for the ANN system. In order to process data in parallel, a network of linked computer processors known as neurons is used. The binary threshold function was used to create the first artificial neuron.[3]

6. AI in Covid-19

The Covid-19 pandemic is a global outbreak of coronavirus, an infectious disease caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) virus. Rapid detection tools have been created by industries and research institutions worldwide in response to the Covid-19 problem. A quick, intelligent method that allows for real-time assessment of the transmission dynamics of disease spread is one of the test kits currently being developed. The preliminary screening of SARS-CoV2-infected individuals is thus being done using AI-based methods, which are now being reviewed. Individuals are checked for potential diseases using AI-based learning frameworks, which then classify them as low, moderate, or high risk.[34]

The goal of several researchers was to create an AI model that could be used to detect Covid-19 in its earliest stages, which would significantly help to slow the pace of transmission. By employing chest X-rays, researchers applied AI algorithms to diagnose Covid-19. Microsoft Custom Vision was trained by the researchers in that project using an object identification system, a dataset of chest X-rays from patients with pneumonia from different etiologist, pneumonia with Covid-19, and normal chest X-rays.[35] One of the most promising classifiers for classification and regression issues is the random forest method (RF), a statistical tool. For the training and prediction of data samples, several trees are employed. Researchers have employed (RF) a lot to try to monitor and regulate Covid-19 pandemic.[36]

7. AI in clinical trials

Inadequate technical infrastructure to handle the complexity of running a trial, especially in its later stages, in the absence of dependable and effective adherence control, patient monitoring, and clinical endpoint detection systems, are two of the main reasons why a clinical trial fail. These factors include patient cohort selection and recruiting mechanisms that fail to bring the best-suited patients to a trial in time.[37] But with the help of AI it can enhance the selection and monitoring of patients.

Digital technologies that evaluate the patient's experience that can transfer significant disease-related changes like wearable technology and mobile applications that can improve patient-centric by identifying practical digital endpoints, advances. AI may be used to examine clinical trial workflow outcomes that how the clinical study will be perform from starting point to end point and find patterns linked to regulatory approval or denial, covering not just effectiveness and safety concerns but also marketing and economic variables.[38]

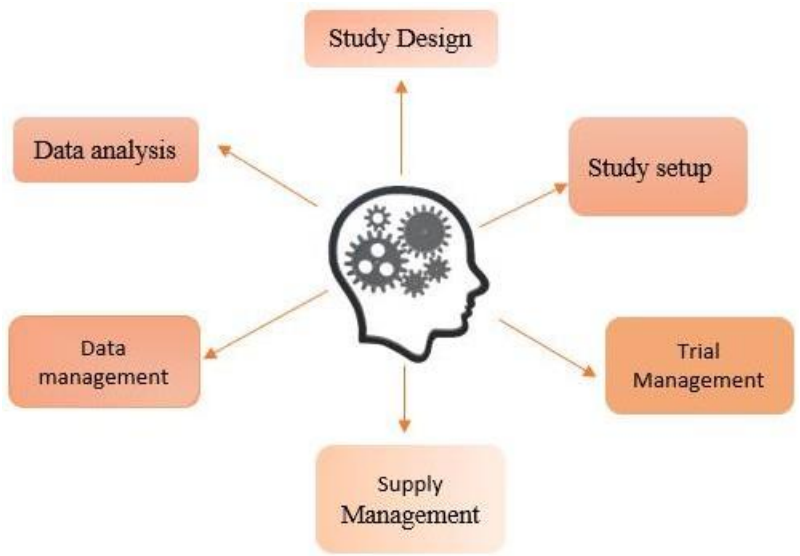

Fig. 3: Automation in clinical trial through AI

Electronic health records (EHRs) are useful tools for recording and exchanging medical information during clinical trials which further reduce reduces time and cost.[39] Data patterns may be found by AI, which can also predict patient behaviour and treatment effectiveness. With the use of this data, researchers may create specialized and successful clinical trials depending on patient characteristics, treatment regimens, and doses. Pharmaceutical firms may simulate how various patient populations will react to certain medications using predictive analytics.[40]

8. Disease diagnosis

Disease diagnosis is the process determining which disease or condition explains a person's symptoms and sign. AI is already being used to help medical professionals and enhance illness detection, such as in the early identification of ectopic pregnancies and assisting gynecologist with their decisions for beginning therapy.[41]

Patients having liver disease may not feel any symptoms while some may have Acute-on-chronic liver failure (ACLF), which results in mortality, can range from asymptomatic liver enzyme abnormalities. As a result, researchers have created prediction models that use often accessible medical and laboratory information to assess the severity and prognosis of many diseases.[42]

Machine learning (ML) techniques have been applied in diagnosis of disease related to heart by several academics and professionals. For example, deep-convolutional-neural-network is an approach used to detect irregular cardiac sound. Alzheimer disease can be diagnosed with the help of Machine Learning tools such as Logistic Reasoning, SVM, and Random Forest (RF). There is another approach that is CNN to detect Alzheimer, CNN shows strong image processing results in comparison to other available algorithms, Alzheimer sufferers are present. [43]

Fig. 4: Working of Convolutional Neural Network

CNN can also use to diagnose life threatening disease like cancer, that has been utilized in gastric cancer with an accuracy of between 86 and 92.5% to automatically discriminate between malignant and non-malignant areas during endoscopy and used to screen patients and determine the extent of intestinal cancer's wall invasion utilizing endoscopic imaging.[44]
Clinical imaging is a process that scan the body of a person for therapeutic objectives, such as locating, examining an injury, pathology, or damage.[41]

9. Current and future perspectives of AI

The artificial intelligence (AI) business is expanding quickly; it went from $200 million in 2015 to $700 million in 2018 and is predicted to reach $5 billion by 2024. The staggering 40% compound annual growth rate between 2017 and 2024 demonstrates how AI will completely transform the pharmaceutical and related industries in the ensuing years.[45] Radiology, cancer, ophthalmology, and basic healthcare decisions have all been demonstrated to benefit from AI/ML-based solutions.
With the help of Machine Learning models, drug compliance, modified insulin dosing and assist with the interpretation of magnetic resonance have been improved.[46] In order to suggest 3D protein structures, identify transcription start sites, construct regulatory elements, and forecast gene expression from genotype data, deep learning has been utilized in conjunction with knowledge from the scientific literature and sequencing discoveries.[47] With the use of the natural language processing approach known as word embedding, words within a vocabulary are expressed as vectors by employing many words to create the text input.[48]
In recent years FDA began to consider a comprehensive regulatory framework based on the product life cycle that would permit revisions based on learning from and adapting to real-world experiences while maintaining the software's safety and efficacy as a medical device.[49]
Simple to sophisticated tasks might be automated in the future of healthcare with the help of AI. Accordingly large volumes of medical data, such lab results or imaging scans, may be analysed by AI to help clinicians find patterns that might go unnoticed by the human sight. As a result, patients may receive more precise diagnosis and treatments from doctors.[50] The studies mostly focus on the use of AI in cardiovascular, neurological system, and cancer problems because these are the primary causes of disability and death.[39]
The clinical validation of recently created basic ideas and tools will be one of the primary challenges of applying AI to medicine in the upcoming years.[51] However, the advancement of AI in medicine has raised worries about the possible impact of this advancement on interpersonal connections, notably between physicians and their patients.[52]

Conclusion

In conclusion, this review paper has given a thorough summary of the enormous influence artificial intelligence (AI) has had on the drug development industry. Artificial intelligence is a useful tool if its use in an appropriate limit with proper knowledge. Upcoming years will be crucial for industry of pharmaceuticals because from drug discovery process to drug manufacturing the AI based model will be implemented in future. These approaches will reduce time and cost during the drug discovery and clinical trial process. In the time of automation, it should not be denied that AI cannot be operated without humans which will help to reduce error during any process.

Regulatory authorities suggests that the goal of discovery or manufacturing of a product should be quality rather than time and cost. Marketing of drugs after the approval is a crucial point which can be done with the algorithms of AI. Collaboration between pharmaceutical professionals, AI researchers, and regulatory agencies will be crucial as AI develops further to fully use its promise while tackling these difficulties. The further development and ethical use of AI have the potential to transform the pharmaceutical industry by enabling more successful, targeted, and effective drug discovery procedures that will eventually benefit patients all around the world.
AI automates and accelerates pharmacovigilance processes, reducing the burden on healthcare professionals and regulatory agencies. This efficiency allows for the rapid identification and response to emerging safety issues, improving overall drug surveillance. AI will continue to be a key component of drug monitoring in the years to come, eventually enhancing patient safety, expediting regulatory procedures, and assisting in the creation of safer and more personalised pharmaceutical therapies. The potential advantages of AI in drug monitoring will only increase as technology advances and more data becomes available.

References

1. Shah N. Artificial Intelligence in Pharma Industry-A Review. Asian Journal of Pharmaceutics (AJP). 2023;17(2).
2. Patel J, Patel D, Meshram D. Artificial Intelligence in Pharma Industry-A Rising Concept. Journal of Advancement in Pharmacognosy. 2021;1(2).
3. Bhattamisra SK, Banerjee P, Gupta P, Mayuren J, Patra S, Candasamy M. Artificial Intelligence in Pharmaceutical and Healthcare Research. Big Data and Cognitive Computing. 2023;7(1):10.
4. Comito C, Pizzuti C. Artificial intelligence for forecasting and diagnosing COVID-19 pandemic: A focused review. Artificial intelligence in medicine. 2022 1; 128:102286.
5. Gupta R, Srivastava D, Sahu M, Tiwari S, Ambasta RK, Kumar P. Artificial intelligence to deep learning: machine intelligence approach for drug discovery. Molecular diversity. 2021:1315-60.
6. Selvaraj C, Chandra I, Singh SK. Artificial intelligence, and machine learning approaches for drug design: challenges and opportunities for the pharmaceutical industries. Molecular diversity. 2021:1-21.
7. Mak KK, Pichika MR. Artificial intelligence in drug development: present status and future prospects. Drug discovery today. 2019;24(3):773-80.
8. Borkotoky S, Joshi A, Kaushik V, Jha AN. Machine Learning and Artificial Intelligence in Therapeutics and Drug Development Life Cycle. IntechOpen; 2022.
9. Machine learning: What it is, tutorial, definition, types-javatpoint (no date) www.javatpoint.com. Available at: https://www.javatpoint.com/machine-learning (Accessed: 22 August 2023).
10. Tarle S, Kakad A, Shaikh Mr. Overview: Embracing Tools of Artificial Intelligence In Pharmaceuticals.2023 Vol. 04, Issue 06
11. Within3. Generative AI and Chatgpt in pharma [Internet]. 2023 [cited 2023 Aug 22]. Available from: https://within3.com/blog/generative-ai-chatgpt-in-pharma.
12. What is Artificial Intelligence (AI)? [Internet]. [cited 2023 Aug 22]. Available from: https://www.ibm.com/topics/artificial-intelligence.
13. [Internet]. [cited 2023 Aug 22]. Available from: https://www.g2.com/articles/history-of-artificial-intelligence.
14. What are the types of artificial intelligence? Branches of ai [Internet]. 2023 [cited 2023 Aug 22]. Available from: https://www.edureka.co/blog/types-of-artificial-intelligence.
15. Four types of AI: Getting to know artificial intelligence [Internet]. [cited 2023 Aug 22]. Available from: https://www.coursera.org/articles/types-of-ai
16. Marko (2023) theory of mind AI: The power of empathy, Medium. Available at:http// pub.towardsai.net/theory-of-mind-AI-the-power-of-empathy(Assessed 22 august 2023)
17. Mea. Self-awareness in Ai [Internet]. Medium; 2020 [cited 2023 Aug 22]. Available from: https://meaxr.medium.com/self-awareness-in-AI.

18. Chen H, Engkvist O, Wang Y, Olivecrona M, Blaschke T. The rise of deep learning in drug discovery. Drug discovery today. 2018;23(6):1241-50.
19. Lu M, Yin J, Zhu Q, Lin G, Mou M, Liu F, Pan Z, You N, Lian X, Li F, Zhang H. Artificial intelligence in pharmaceutical sciences. Engineering. 2023.
20. Dreiseitl S, Ohno-Machado L. Logistic regression and artificial neural network classification models: a methodology review. Journal of biomedical informatics. 2002 ;35(5-6):352-9.
21. Senior AW, Evans R, Jumper J, Kirkpatrick J, Sifre L, Green T, Qin C, Žídek A, Nelson AW, Bridgland A, Penedones H. Protein structure prediction using multiple deep neural networks in the 13th Critical Assessment of Protein Structure Prediction (CASP13). Proteins: structure, function, and bioinformatics. 2019 ;87(12):1141-8.
22. Burley SK, Berman HM. Open-access data: A cornerstone for artificial intelligence approaches to protein structure prediction. Structure. 2021 ;29(6):515-20.
23. Prasad K, Kumar V. Artificial intelligence-driven drug repurposing and structural biology for SARS-CoV-2. Current Research in Pharmacology and Drug Discovery. 2021 1; 2:100042.
24. Schenone M, Dančík V, Wagner BK, Clemons PA. Target identification and mechanism of action in chemical biology and drug discovery. Nature chemical biology. 2013;9(4):232-40.
25. Liu Z, Roberts RA, Lal-Nag M, Chen X, Huang R, Tong W. AI-based language models powering drug discovery and development. Drug Discovery Today. 2021;26(11):2593-607.
26. Qureshi R, Irfan M, Gondal TM, Khan S, Wu J, Hadi MU, Heymach J, Le X, Yan H, Alam T. AI in Drug Discovery, and its Clinical Relevance. Heliyon. 2023.
27. Paul D, Sanap G, Shenoy S, Kalyane D, Kalia K, Tekade RK. Artificial intelligence in drug discovery and development. Drug discovery today. 2021(1):80.
28. Öztürk H, Özgür A, Ozkirimli E. DeepDTA: deep drug–target binding affinity prediction. Bioinformatics. 2018;34(17): i821-9.
29. Raies AB, Bajic VB. In silico toxicology: computational methods for the prediction of chemical toxicity. Wiley Interdisciplinary Reviews: Computational Molecular Science. 2016;6(2):147-72.
30. Basile AO, Yahi A, Tatonetti NP. Artificial intelligence for drug toxicity and safety. Trends in pharmacological sciences. 2019;40(9):624-35.
31. Awwalu J, Garba AG, Ghazvini A, Atuah R. Artificial intelligence in personalized medicine application of AI algorithms in solving personalized medicine problems. International Journal of Computer Theory and Engineering. 2015;7(6):439.
32. Chakravarty K, Antontsev V, Bundey Y, Varshney J. Driving success in personalized medicine through AI-enabled computational modeling. Drug Discovery Today. 2021 1;26(6):1459-65.
33. GS G. Personalized medicine: revolutionizing drug discovery and patient care. Trends Biotechnol. 2001; 19:491-6.
34. Malik YS, Sircar S, Bhat S, Ansari MI, Pande T, Kumar P, Mathapati B, Balasubramanian G, Kaushik R, Natesan S, Ezzikouri S. How artificial intelligence may help the Covid-19 pandemic: Pitfalls and lessons for the future. Reviews in medical virology. 2021(5):1-1.
35. Khan M, Mehran MT, Haq ZU, Ullah Z, Naqvi SR, Ihsan M, Abbass H. Applications of artificial intelligence in COVID-19 pandemic: A comprehensive review. Expert systems with applications. 2021 15; 185:115695.
36. Harrer S, Shah P, Antony B, Hu J. Artificial intelligence for clinical trial design. Trends in pharmacological sciences. 2019 1;40(8):577-91.
37. Delso G, Cirillo D, Kaggie JD, Valencia A, Metser U, Veit-Haibach P. How to design AI-driven clinical trials in nuclear medicine. InSeminars in nuclear medicine 2021 (Vol. 51, No. 2, pp. 112-119). WB Saunders.
38. Cirillo D, Catuara-Solarz S, Morey C, Guney E, Subirats L, Mellino S, Gigante A, Valencia A, Rementeria MJ, Chadha AS, Mavridis N. Sex and gender differences and biases in artificial intelligence for biomedicine and healthcare. NPJ digital medicine. 2020 ;3(1):81.
39. Noorbakhsh-Sabet N, Zand R, Zhang Y, Abedi V. Artificial intelligence transforms the future of health care. The American journal of medicine. 2019 Jul 1;132(7):795-801.

40. Jolly J. How AI is revolutionizing clinical trials and research? [Internet]. Saxon. 2023 [cited 2023]. Available from: https://saxon.ai/blogs/empowering-clinical-trials-and-research-impact-of-ai-in-medicine
41. Mirbabaie M, Stieglitz S, Frick NR. Artificial intelligence in disease diagnostics: A critical review and classification on the current state of research guiding future direction. Health and Technology. 2021;11(4):693-731.
42. Ahn JC, Connell A, Simonetto DA, Hughes C, Shah VH. Application of artificial intelligence for the diagnosis and treatment of liver diseases. Hepatology. 2021;73(6):2546-63.
43. Ahsan MM, Luna SA, Siddique Z. Machine-learning-based disease diagnosis: A comprehensive review. InHealthcare (Vol. 10, No. 3, p. 541). MDPI 2022.
44. Deng Y, Qin HY, Zhou YY, Liu HH, Jiang Y, Liu JP, Bao J. Artificial intelligence applications in pathological diagnosis of gastric cancer. Heliyon. 2022 Dec.
45. Kalyane D, Sanap G, Paul D, Shenoy S, Anup N, Polaka S, Tambe V, Tekade RK. Artificial intelligence in the pharmaceutical sector: current scene and future prospect. InThe future of pharmaceutical product development and research 2020 (pp. 73-107). Academic Press.
46. Benjamens S, Dhunnoo P, Meskó B. The state of artificial intelligence-based FDA-approved medical devices and algorithms: an online database. NPJ digital medicine. 2020;3(1):118.
47. Johnson KB, Wei WQ, Weeraratne D, Frisse ME, Misulis K, Rhee K, Zhao J, Snowdon JL. Precision medicine, AI, and the future of personalized health care. Clinical and translational science. 2021(1):86-93.
48. Popa SL, Pop C, Dita MO, Brata VD, Bolchis R, Czako Z, Saadani MM, Ismaiel A, Dumitrascu DI, Grad S, David L. Deep learning, and antibiotic resistance. Antibiotics. 2022 Nov 21;11(11):1674.
49. Food and Drug Administration. Proposed regulatory framework for modifications to artificial intelligence/machine learning (AI/ML)-based software as a medical device (SaMD) 2019.
50. King MR. The future of AI in medicine: a perspective from a Chatbot. Annals of Biomedical Engineering. 2023;51(2):291-5.
51. Briganti G, Le Moine O. Artificial intelligence in medicine: today and tomorrow. Frontiers in medicine. 2020; 7:27.
52. Hatherley JJ. Limits of trust in medical AI. Journal of medical ethics. 2020 ;46(7):478-81.