IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 1, May 2024

Role of Artificial Intelligence in Pharmacy

Ms. S. S. Satkar[1], Ms. P. A. Jadhav[2], Mr. T. A. Randhe[3]
Assistant Professor. Department of Pharmaceutical Sciences[1]
Final Y. B. Pharm Student, Department of Pharmaceutical Sciences[2,3]
IVM's Krishnarao Bhegade Institute of Pharmaceutical Education & Research, Talegaon Dabhade, India

Abstract: *The use of artificial intelligence in pharmaceutical technology has grown over time. This is because technology may be used to save costs and time, as well as to better comprehend the interactions between various formulations and process parameters. A subfield of computer science called artificial intelligence studies problem-solving with the use of symbolic programming. It has significantly advanced into a science of problem-solving with numerous applications in engineering, business, and healthcare. Artificial intelligence has enormous potential for solving health-related issues First of all. Artificial intelligence (AI) approaches have reached a degree of maturity where they can be used to support human decision-makers in real-world scenarios. Artificial Intelligence (AI) holds promise for revolutionising clinical trial design, from study planning to trial execution, with the goal of increasing trial success rates and reducing pharmaceutical R&D costs. The present study explain various pharmaceutical areas in AI plays an important role for development and growth of pharmaceutical industry.*

Keywords: Tools of AI, challenges to adoption of AI in pharma, application of AI, drug discovery, Artificial Intelligence

I. INTRODUCTION

In recent times, artificial intelligence (AI) has emerged as a highly successful multidisciplinary approach, particularly in the fields of machine learning (ML) and deep learning (DL).[2] The technological society in which we live produces enormous amounts of data annually in nearly every field. Artificial Intelligence helps humans manage the massive volume of data. Therefore, large database-producing scientific societies are regarded as ML's component. These days, machines help people with manual labour and can accelerate development at every level. Humans are inferior to machines in a number of areas, including analysis, learning, and communication comprehension. By creating and applying sophisticated computer programmes, machine learning (ML) can evaluate large amounts of data without the need for human participation. It can also help with several phases of drug discovery, including pharmacological research like lead compound identification.[3]

Artificial intelligence (AI) is a branch of science that studies intelligent machine learning, specifically intelligent computer programs that generate results similar to those of human attention processes.[4] The field of artificial intelligence is one that is expanding quickly and has many uses in business and daily life. Recently, the pharmaceutical industry has discovered innovative and imaginative ways to use this powerful technology to help address some of the most urgent problems facing the sector at the moment. Artificial intelligence in the pharmaceutical sector refers to the use of automated algorithms to do tasks that have traditionally required human intelligence. Over the past five years, artificial intelligence has completely changed the pharmaceutical and biotech industries in terms of how researchers are able to cure ailments, develop new drugs, and much more.[5]

BASICS OF ARTIFICIAL INTELLIGENCE:

Only when a machine has the ability to store activity-related information can it respond and acts like a human. Artificial intelligence can evaluate items, attributes, classifications, and relationships among them by using data encoded within it. Start with common sense; it is highly challenging to develop logical reasoning and the capacity for problem-solving in machines. The core component of artificial intelligence (AI) learning is machine learning, which involves identifying patterns in the flow or run of inputs without the use of commands. Other learning capabilities include classification and numerical regressions. The process of determining the category's conclusion involves classifying an object, performing regression analysis, and obtaining a set of numerical output or input examples. This allows for the discovery of new functions that enable the production of acceptable and satisfactory outputs from the given inputs.[6]

ADVENTAGES OF AI TECHNOLOGY;

The potential advantages of AI technology are as follows:[7,8,9]

- *Error minimization:* AI helps to more precisely raise accuracy and reduce errors. Intelligent robots are sent to explore space because their metal bodies are resistant and they can withstand the harsh atmosphere there.
- *Difficult exploration:* Mining is one area where artificial intelligence is useful. The field of fuel exploration also makes use of it. Artificial intelligence (AI) systems have the ability to overcome human error and conduct ocean research.

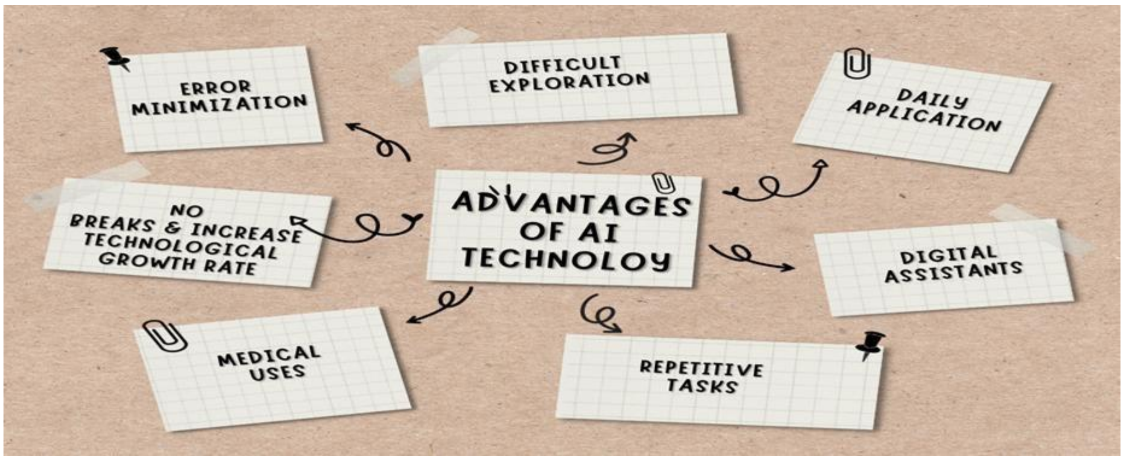

Fig. 2 Advantage of AI

- *Daily application:* Artificial Intelligence greatly benefits our day-to-day actions. For instance, long drives are a common use for GPS systems. Android devices with AI installed can anticipate what a user will type. Spelling errors can also be corrected with its assistance.
- *Digital assistants:* To reduce the need for human labour, modern, advanced organizations are utilizing artificial intelligence (AI) systems like "avatars," which are models of digital assistants. The "avatar" is capable of making the proper, logical choices because they are devoid of any emotion. Artificial intelligence (AI) can be used to solve the problem of human emotions and moods impairing judgment.
- *Repeated tasks:* People can typically handle one repetitive task at a time. Comparatively speaking, machines can do tasks that require multiple tasks at once and analyse data faster than humans. It is possible to modify different machine parameters, such as speed and time, based on specific needs.
- *Medical applications:* Generally speaking, doctors can use AI programs to evaluate patients' conditions and examine side effects and other health risks related to medication. With the use of AI applications, such as different artificial surgery simulators (such as those that simulate the heart, gastrointestinal tract, brain, etc.), trainee surgeons can learn a lot.
- *No breaks:* Unlike humans, who can work for eight hours a day with breaks, machines are designed to be able to work continuously for extended periods of time without experiencing any form of boredom or confusion.
- *Accelerate the rate of technological advancement:* AI is a major component of the majority of cutting-edge technological advancements made globally. It aims at the creation of newer molecules and can generate various computational modelling programs. Moreover, AI technology is being applied to the creation of drug delivery formulations.

DISADVANTAGES OF AI TECHNOLOGY:

The important disadvantages of AI technology are as follows:

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 1, May 2024

Fig. 3 Disadvantages of AI

- *Expensive:* Adopting AI requires large financial outlays. The cost of designing, maintaining, and repairing complex machines is quite low. It takes a lot of time for the research and development department to create a single AI system. An AI machine's software needs to be updated regularly. Reinstallations and computer recovery are expensive and time-consuming processes.
- *No human replication:* Robots with artificial intelligence (AI) capabilities are claimed to have human-like emotionlessness and cognitive processes, which offers advantages including improved task accuracy and objective performance. Robots can't make decisions when new problems arise, and they might provide false information.
- *Experience doesn't improve human resources:* Experience does improve human resources. On the other hand, AI-powered machines are incapable of learning from experience. They are unable to distinguish between the hard-working and nonworking individuals.
- *Lack of original creativity:* AI-enabled machines lack both emotional intelligence and sensitivity. People are able to see, hear, feel, and think. They are able to employ both their imagination and reasoning. Machines are not capable of achieving these features.
- *Jobless rates:* The extensive application of AI technology across all industries could result in high rates of joblessness. Due to unfavourable unemployment, employees may become less creative and prone to bad work habits.

CLASSIFICATION OF AI

AI can be divided into the following categories based on whether it is now existent or not:

- *Type 1:* Because it lacks a memory system, it is only useful for narrow applications where past experiences cannot be leveraged. It's referred to as a reactive machine. A chess program developed by IBM is one example of this memory in action; it can identify the checkers on the chess board and make predictions.
- *Type 2:* It has a restricted memory system that allows it to use prior knowledge to solve various issues. Automatic car systems have the ability to make decisions based on recorded observations. These observations are used to record subsequent actions, but the records are not kept indefinitely.
- *Type 3:* "Theory of Mind" serves as the basis. It suggests that individuals' distinct methods of intending, wanting, and thinking affect the choices they make. This system is an example of non-existent AI.
- *Type 4:* It has a sense of self and is cognizant and self-aware. Furthermore, this system isn't even AI.

ROLE OF ARTIFICIAL INTELLIGENCE IN PHARMA

The pharmaceutical industry can leverage technology breakthroughs to drive innovation. The most recent technological development that springs to mind is artificial intelligence, or the creation of computer systems capable of carrying out operations that would typically require human intelligence, like speech recognition, visual perception, decision-making, and language translation. According to an estimate from IBM, as of 2011, the entire Healthcare domain contained approximately 161 billion GB of data. The vast amount of data in this field makes artificial intelligence a valuable tool for data analysis and result presentation. This can aid in decision making, save human effort, time, and expense, and potentially save lives. Epidermis outbreak prediction: by utilizing machine learning and artificial intelligence, one can examine the past of previous outbreaks, examine social media activity, and forecast the location and timing of outbreaks with a high degree of accuracy.[11]

In addition to the use cases already mentioned, there is a ton more, such as: Customizing the course of treatment; assisting in the development of new instruments for patients, doctors, etc. Research on clinical trials: using predictive analytics to find trial candidates by social media and visits to doctors.

VARIOUS APPLICATION IN PHARMACEUTICAL FIELD

A. In Formulation:

Controlled release tablets: Hussain and colleagues at the University of Cincinnati (OH, USA) completed the first study using neural networks to model pharmaceutical formulations. They modelled the in vitro release properties of multiple medicines distributed in a matrix made up of different hydrophilic polymers in a number of studies. Neural networks were discovered to function rather effectively in every situation when it comes to drug release prediction while using a single hidden layer.[12]

In a more recent study involving the formulation of diclofenac sodium from a matrix tablet prepared from acetyl alcohol, personnel from the pharmaceutical company KRKA (Smerjeska, Slovenia) and the University of Ljubljana (Slovenia) employed neural networks to predict the rate of drug release and to carry out optimization using two- and three-dimensional response surface analysis.[13]

B. Immediate release tablets:

Just three years ago, two papers signalled the start of this field's research. In one, Turkoglu and colleagues used statistics and neural networks to model hydrochlorothiazide pill formulations. They were affiliated with the Universities of Cincinnati and Marmara (Turkey).

The networks developed were used to build three-dimensional plots of massing time, compression pressure, and crushing strength, or drug release, massing time, and compression pressure, in an attempt to optimize tablet strength or select the best lubricant. Despite the observed trends, no ideal formulations were provided. The patterns matched those produced by statistical methods. Similar neural network models were created, and genetic algorithms were used to optimize them. It was discovered that the ideal formulation was determined by the limitations imposed on the amounts of ingredients utilized in the formulation and the proportionate weight given to the output parameters. It was only possible to achieve low friability and high tablet strength at the cost of longer disintegration times. Lactose was the favoured diluent in every instance, and fluidized bed was the favoured granulating method.[15]

C. In Product Development:

The process of creating pharmaceuticals is a multivariate optimization problem. It involves optimizing process variables and formulas. One of the best things about artificial neural networks is that they can generalize. Because of these qualities, they can be used to address formulation optimization problems in the creation of pharmaceutical products.[16] When it came to creating solid dosage forms, ANN models showed better fitting and prediction abilities when analysing the impact of several parameters (like formulation and compression parameters) on tablet characteristics (like dissolving). ANNs were a useful tool in the creation of micro emulsion-based, minimally invasive medication delivery devices.

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 1, May 2024

D. In Drug Discovery

Among the leading biopharmaceutical companies' current AI initiatives are:

A mobile platform that uses real-time data collection to make patient recommendations that improve patient outcomes.

Software firms and pharmaceutical corporations are working together to incorporate cutting-edge technologies into the costly and time-consuming drug discovery process.[17]

One common phase in the protracted drug discovery process is testing chemicals against samples of sick cells. To find chemicals that are biologically active and deserving of more research, more analysis is required.

Novartis research teams use images from machine learning algorithms to predict which untested compounds might be worth further investigation, which expedites the screening process. New and efficient medications can be made available sooner thanks to computers' significantly faster discovery of new data sets than traditional human analysis and laboratory experiments. This also lowers the operational costs related to the labour-intensive manual investigation of each compound. Even with its benefits, AI still has to deal with a lot of data, including data size, growth, diversity, and uncertainty. Millions of compounds may be present in the drug development data sets made available to pharmaceutical companies; conventional machine learning tools may not be able to handle this kind of data. A computational model based on the quantitative structure-activity relationship (QSAR) can predict a large number of compounds or basic physicochemical parameters like log P or log D very quickly. Nevertheless, these models are not very good at forecasting complex biological traits like drug efficacy and adverse effects.[21]

E. In Pharmaceutical Manufacturing

The increasing complexity of manufacturing processes and the need for greater productivity and better product quality are driving changes in manufacturing practices, and modern manufacturing systems are striving to transfer human knowledge to machines.[22] The novel Computer platform integrates various chemical codes to enable digital automation for the synthesis and manufacture of molecules through the use of a scripting language called Chemical Assembly.[23]

The synthesis and production of ralfinamide, diphenhydramine hydrochloride, and sildenafil have all been accomplished with success; the yield and purity are noticeably comparable to those of manual synthesis.[24] In the pharmaceutical industry, DEM is widely used for research purposes. Examples of applications include analysing the time that tablets spend under the spray zone, predicting the possible path of the tablets during the coating process, and studying the segregation of powders in a binary mixture.[25] AI tools called tablet-classifier and meta-classifier assist in regulating the final product's quality standard by flagging potential manufacturing errors in tablets.[26]

F. In Quality Control And Quality Assurance

A variety of factors must be balanced in order to manufacture the desired product from the raw materials.[27] Manual intervention is needed to maintain batch-to-batch consistency and conduct quality control tests on the products. This may not be the optimal course of action in every situation, highlighting the necessity of implementing AI at this time. Artificial Intelligence (AI) has the potential to regulate in-line manufacturing processes in order to attain the intended product standard.[28] Utilizing a combination of local search, back propagation, and self-adaptive evolution, ANN-based monitoring of the freeze-drying process is used. This can eventually aid in maintaining control over the quality of the finished product by predicting the temperature and desiccated-cake thickness at a future time point ($t + Dt$) for a specific set of operating conditions.[29]

The product's quality assurance can be ensured by combining sophisticated, perceptive procedures with an automated data entry platform, such as an Electronic Lab Notebook.[30] Furthermore, data mining and other knowledge discovery methods inside the Total Quality Management expert system can be helpful in the development of new technologies for intelligent quality control and in supporting intricate decision-making.[31]

G. In Clinical Trial Design

To determine a therapeutic product's safety and efficacy in people for a particular illness condition, clinical trials require a substantial financial investment and duration of six to seven years. Unfortunately, the industry loses a lot of money because only one molecule out of ten that goes through these studies gets approved.[32] Patient enrolment takes up one-third of the trial's time. A clinical trials effectiveness depends on selecting the correct patients, as 86% of failure cases occur when this isn't done.[33] While keeping the selected patient group in mind, preclinical molecule discovery and early lead compound prediction employing additional AI elements, such as predictive machine learning and other reasoning techniques, help in the early identification of lead molecules that would pass clinical trials. Patient dropouts account for thirty percent of clinical trial failures, resulting in additional recruiting criteria needed to finish the trial and wasting money and time. Close patient observation and support in following the specified clinical trial procedure can help avoid this.[35] Ai Cure created mobile software to track schizophrenia patients' consistent medication intake during a Phase II trial. This resulted in a 25% increase in patient adherence and the successful completion of the clinical trial.

H. In Pharmaceutical Product Management

Market positioning, which is the process of giving a product a personality in the marketplace to entice customers to purchase it, is a crucial component of most business strategies for organizations looking to forge their own distinctive identities.[36, 37] This strategy was applied in the promotion of the original Viagra brand, which the business marketed to treat other issues impacting quality of life in addition to erectile dysfunction in men.[38] Technology and e-commerce as a platform have made it simpler for businesses to establish their brand's organic recognition in the public sphere. As the Internet Advertising Bureau has also confirmed, businesses use search engines as one of the technology platforms to take centre stage in online marketing and aid in the positioning of the product in the market. Businesses constantly strive to make their websites rank higher than those of competitors, which quickly establishes their brand.[39]

I. In Hospital Pharmacy

AI is being used in hospital pharmacy-based health care systems in a number of ways, including selecting appropriate or available administration routes, treatment policies, and organizing dosage forms for individual patients.

- Updating medical records: Keeping up with patients' medical records is a difficult task. The AI system makes data collection, storage, normalization, and tracing easier. The Google Deep Mind health project facilitates the expeditious excavation of medical records. Thus, this project is helpful in providing faster and better healthcare.
- Creating treatment plans: AI technology makes it feasible to create efficient treatment plans. An artificial intelligence (AI) system is required to take control of the situation when a patient develops a critical condition and choosing an appropriate treatment plan becomes challenging
- Assisting with repetitive tasks: Another area where artificial intelligence (AI) technology is useful is in the analysis of radiology, X-ray imaging, ECHO, ECG, and other tests that are used to discover and detect diseases or problems.

Help with health and medication: It has been recognized recently that the use of AI technology can be beneficial in offering both health support services and pharmaceutical help. Patients can monitor their status and receive assistance from an app called Ai Cure, which tracks them via their smartphone's webcam.

J. To Predict New Treatments

Verge is addressing the primary issues in drug discovery through automated data collection and analysis. To put it another way, they are mapping out hundreds of genes that have intricate roles in brain disorders like ALS, Parkinson's, and Alzheimer's by using an algorithmic approach. Verge posits that the collection and analysis of gene data will have a beneficial effect on the drug discovery process, beginning with preclinical trials. The idea is that Verge can monitor, beginning in the preclinical stage, the effects that particular drug treatments have on the human brain using artificial intelligence. Consequently, pharmaceutical companies can obtain a more accurate early-stage picture regarding a drug's efficacy on human cells. More particular, Verge employs artificial intelligence to monitor the effects of specific treatments on the human brain, with an emphasis on the preclinical stage.

TOOLS OF ARTIFICIAL INTELLEGENCE

Numerous instruments have been created to tackle the diverse problems confronting the pharmaceutical sector. The techniques have yielded positive outcomes. Here are a few well-known instruments that have become incredibly popular.

a. IBM Watson for oncology

Supercomputers dubbed Watson are developed by IBM. To answer questions, a combination of advanced analytical software and artificial intelligence device design is used. It is intended to help oncologists make better decisions when treating cancer. It assigns treatment options based on the information gathered by evaluating a patient's medical data from a vast network of data and expertise. It works well for deciphering context and meaning from clinical notes and reports, whether they are appropriately structured or not. It can simply compile analytical data about the patient and write it in understandable terms, which can prove to be a crucial step in giving the patient the right treatment plan.It combines important aspects from the patient file with data, clinical research, and outside research to determine or recommend the best possible treatment plans for the patient. Watson has amassed a vast collection of data from over 200 textbooks, 12 million text pages, over 290 medical journals, and rationales selected by MSK.[43]

b. Robot pharmacy

To increase patient safety, UCSF Medical Centre uses robotic technology for drug preparation and tracking. They assert that 3,50,000 doses of medication have been successfully and nearly error-free manufactured by the technology. The robot has proven to be much more accurate at delivering medication than people, and it is also smaller. Robotic technology can be used to produce injectable and oral drugs, including hazardous chemotherapy medications. Together with the doctors, the UCSF nurses and pharmacists can now focus on direct patient care, giving them greater opportunities to hone their talents.[44]

c. MEDi robot

MEDi is well-known for its engineering design intelligence and medicine. An Albertan professor of community health sciences at the University of Calgary oversaw a pain management robot project. When she was working in a hospital and witnessed children screaming during medical procedures, she got the idea to build this robot.[45] After establishing a cordial rapport with the kids, the robot explains to them what to expect during a medical procedure. It provides them with instructions on what to do, how to breathe, and how to handle the medical procedure.[46]

d. Erica robot

Erica is a novel care robot designed by Hiroshi Ishiguro, a professor at Osaka University in Japan. Erica was developed by the Japan Science and Technology Agency, Kyoto University, and the Advanced Telecommunications Research Institute International (ATR). It speaks Japanese and has a mixed Asian and European face.[47] Like any other typical person, it wishes to have a life partner with whom it might have conversations. It also likes to watch animated films and visit countries in Southeast Asia. While the robot is unable to move on its own, it is capable of understanding inquiries and responding with human-like facial expressions. Ishiguro created the robot's nose, eyes, and other attributes by averaging the features of thirty attractive women. Erica is the "most beautiful and intelligent" android.[48]

FUTURE SCOPE

AI's primary potential in the pharmaceutical sector is to lower costs and boost productivity. Numerous studies have shown that dynamic learning, as opposed to traditional AI and information sub sampling approaches, can distinguish remarkably accurate AI models with half or less information. Though the exact cause of this improved productivity is unknown, it seems that fewer repetitions and predispositions, along with obtaining more important data to translate choice limits, are important factors in this better execution. Therefore, screening costs seem to be lowered by as much as 90% without accounting for the anticipated mechanical overhead for actually carrying out dynamic learning efforts.

II. CONCLUSION

Humans are the most unpredictable, creative, and creative knowledge-storing machines that have ever existed. However, this statement was only true a few years or decades before artificial intelligence (AI) was created. A.I. is 1000 times quicker, error-free, cost- and time-efficient, and capable of doing tasks more quickly than humans. However, keep in mind that artificial intelligence (AI) was developed exclusively by humans. Let's examine whether this technology turns into hell or paradise, as Stephen Hawking famously predicted, "This may mean the end of human race." Everything has two sides: a GOOD side and a BAD side. However, as AI has evolved, the number of humans has decreased.

Even while AI can expedite the creation of new drugs, actual studies must still be carried out. Furthermore, gene therapy and other therapies that is not now available to us as medical instruments can benefit from the assistance of AI. Along with AI, the prospect of merging gene therapy, pharmacology, and regenerative medicine appears. Redesigning clinical trial designs and applying AI tools to do so are crucial components of a much-needed drug development cycle revamp.

ABBREVIATIONS

Relationships between quantitative structure and activity (QSAR) and properties (QSPR) are demonstrated by artificial neural networks (ANN), deep neural networks (DNN), generative adversarial networks (GAN), artificial general intelligence (AGI), artificial narrow intelligence (ANI), and so forth. RNN is an acronym for Recurrent Neural Network, and SAS is an acronym for Synthetic Accessibility Score.

REFERENCES

[1]. Ch.Krishnaveni, Swarupa Arvapalli, J.V.C Sharma, Divya.K. Artificial Intelligence In Pharma Industry- A Review. International Journal of Innovative Pharmaceutical Sciences and Research, 2019. 7 (10), 37-50. DOI: 10.21276/IJIPSR.2019.07.10.506

[2]. Ayyappa Chaturvedula, Stacie Calad-Thomson, Chao Liu, Mark Sale, et al. Artificial Intelligence and Pharmacometrics: Time to Embrace, Capitalize, and Advance? CPT: Pharmacometrics & Systems Pharmacology, 2019. 8(7):440-443. doi: 10.1002/psp4.12418.

[3]. Amara Jabeen, Shoba Ranganathan. Applications of machine learning in GPCR bioactive ligand discovery. Current Opinion in Structural Biology. 2019; 55:66-76. doi: 10.1016/j.sbi.2019.03.022.

[4]. Kit-Kay Mak, Mallikarjuna Rao Pichika. Artificial intelligence in drug development: Present status and future prospects. Drug Discovery Today. 2019; 24(3):773-780. doi: 10.1016/j.drudis.2018.11.014.

[5]. Saurabh G. ingle, Shailesh G. Jawarkar, Snehaja Bhalerao, Piyusha Gulhane, et al. Review On: Artificial Intelligence (AI) In Pharmacy. Journal of Emerging Technologies and Innovative Research, 2023. 1(1):97-112. DOI: http://doi.one/10.1729/Journal.33638

[6]. Statistica. Artificial Intelligence (AI). Available from: https://www.statista.com/study/38609/artificial-intelligence-ai-statista-dossier/. [Last accessed on 2017 Jun 24].

[7]. Fei Jiang, Yong Jiang, Hui Zhi, Yi Dong, et al. Artificial intelligence in healthcare: past, present and future. Stroke and Vascular Neurology, 2017;2(4):230-243. doi: 10.1136/svn-2017-000101.

[8]. S.S. Manikiran, N.L. Prasanthi. Artificial Intelligence: Milestones and Role in Pharma and Healthcare Sector. Pharma Times, 2019; 51 (01):9-15.

[9]. David Silver, Julian Schrittwieser, Karen Simonyan, Ioannis Antonoglou, et al. Mastering the game of Go without human knowledge. Nature, 2017; 550:354–359. https://doi.org/10.1038/nature24270.

[10]. Sudipta Das, Rimi Dey, Amit Kumar Nayak. Artificial Intelligence in Pharmacy. Indian Journal of Pharmaceutical Education and Research, 2021; 55(2):304-318. doi:10.5530/ijper.55.2.68.

[11]. http://refhub.elsevier.com/S1359-6446(18)30091-6/sbref0035

[12]. R.C. Rowe and R.J Roberts. "Artificial intelligence in pharmaceutical product formulation: neural computing and emerging technologies", PSTT, vol. 1, pp. 200-205, 1998.

[13]. C. Hayes and T. Gedeon, Hyperbolicity of the fixed point set for the simple genetic algorithm, Theoretical Computer Science,2010; 411(25): 2368–2383.

[14]. Di Masi, J.A. et al. The cost of drug development. N. Engl. J. Med.,2015: 372. http://dx.doi.org/10.1056/NEJMc1504317

[15]. David E. Goldberg. Genetic algorithms in search, optimization and machine learning. Addison Wesley. Addison-Wesley Publishing Company Inn, 1989.

[16]. K.F. Man, K.S. Tang, S. Kwong. Genetic algorithms: concepts and applications [in engineering design]. IEEE Transactions on Industrial Electronics, 1996; 43(5): 519 – 534. DOI: https://doi.org/10.1109/41.538609.

[17]. Dina Bass. Microsoft Develops AI to Help Cancer Doctors Find the Right Treatments, 2016. (https://www.bloomberg.com/news/articles/2016-09-20/microsoft-develops-ai-to-help-cancer-doctors-find-the -right-treatments).

[18]. Hao Zhu. Big Data and Artificial Intelligence Modeling for Drug Discovery. Annual Review of Pharmacology and Toxicology, 2020; 60:573-589. DOI: 10.1146/annurev-pharmtox-010919-023324.

[19]. Heather L. Ciallella and Hao Zhu. Advancing Computational Toxicology in the Big Data Era by Artificial Intelligence: Data-Driven and Mechanism-Driven Modeling for Chemical Toxicity. Chemical Research in Toxicology, 2019; 32(4): 536–547. doi: 10.1021/acs.chemrestox.8b00393.

[20]. H C Stephen Chan, Hanbin Shan, Thamani Dahoun, Horst Vogel. Advancing Drug Discovery via Artificial Intelligence. Trends in Pharmacological Sciences, 2019;40(8):592-604. doi: 10.1016/j.tips.2019.06.004.

[21]. Matthew A Sellwood, Mohamed Ahmed, Marwin Hs Segler, Nathan Brown. Artificial intelligence in drug discovery. Future Medicinal Chemistry,2018;10(17):2025-2028. doi: 10.4155/fmc-2018-0212.

[22]. Lu Zhang, Jianjun Tan, Dan Han, Hao Zhu. From machine learning to deep learning: progress in machine intelligence for rational drug discovery. Drug Discovery Today, 2017;22(11):1680-1685. doi: 10.1016/j.drudis.2017.08.010.

[23]. Jukka Rantanen and Johannes Khinast. The Future of Pharmaceutical Manufacturing Sciences. Journal of Pharmaceutical Sciences, 2015; 104(11): 3612–3638. doi: 10.1002/jps.24594.

[24]. Sebastian Steiner, Jakob Wolf, Stefan Glatzel, Anna Andreou, et al. Organic synthesis in a modular robotic system driven by a chemical programming language. SCIENCE,2018; 363(6423).DOI: 10.1126/science.aav2211.

[25]. Matjaž Gams, Matej Horvat, Matej Ožek, Mitja Luštrek, and Anton Gradišek. Integrating Artificial and Human Intelligence into Tablet Production Process. AAPS PharmSciTech, 2014; 15(6): 1447–1453. DOI: 10.1208/s12249-014-0174-z.

[26]. Farid Meziane, Sunil Vadera, Khiary Kobbacy and Nathan Proudlove. Intelligent Systems in Manufacturing: Current Developments and Future Prospects. Integrated Manufacturing Systems, 2000; 11(4):218-238. DOI: 10.1108/09576060010326221.

[27]. Chunhua Zhao, Ankur Jain, Leaelaf Hailemariam, Pradeep Suresh, et al. Toward intelligent decision support for pharmaceutical product development. Journal of Pharmaceutical Innovation, 2006; 1(1):23-35. DOI:10.1007/BF02784878.

[28]. Xiaoh Wang. Intelligent Quality Management Using Knowledge Discovery in Databases. 2009 International Conference on Computational Intelligence and Software Engineering, 2009. DOI: 10.1109/CISE.2009.5364999.

[29]. David B. Fogel. Factors associated with clinical trials that fail and opportunities for improving the likelihood of success: A review. Contemporary Clinical Trials, 2018; 11: 156–164. doi: 10.1016/j.conctc.2018.08.001.

[30]. Buket Aksu, Anant Paradkar, Marcel de Matas, Özgen Özer, et al. A quality by design approach using artificial intelligence techniques to control the critical quality attributes of ramipril tablets manufactured by wet granulation. Pharmaceutical Development and Technology, 2013;18(1):236-45. doi: 10.3109/10837450.2012.705294.

[31]. Drăgoi, E. N., Curteanu, S., & Fissore, D. On the Use of Artificial Neural Networks to Monitor a Pharmaceutical Freeze-Drying Process. Drying Technology, 2013; 31(1):72–81. DOI: https://doi.org/10.1080/07373937.2012.718308.

[32]. Hay M, Thomas DW, Craighead JL, Economides C, Rosenthal J. Clinical development success rates for investigational drugs. Nature Biotechnology, 2014;32(1):40-51. doi: 10.1038/nbt.2786.

[33]. Chui-Yu Chiu, Yi-Feng Chen, I-Ting Kuo, He Chun Ku. An intelligent market segmentation system using k-means and particle swarm optimization. Expert Systems with Applications, 2009; 36, I(3), : 4558-4565. DOI: https://doi.org/10.1016/j.eswa.2008.05.029.

[34]. Bower P., Wallace P., Ward E., Graffy J., Miller J., Delany B., Kinmonth A.L. Improving recruitment to health research in primary care. Fam. Pract. 2009;26:391–397. doi: 10.1093/fampra/cmp037.

[35]. Stefan Harrer, Pratik Shah, Bhavna Antony, and Jianying Hu. Artificial Intelligence for Clinical Trial Design. Trends in Pharmacological Sciences, 2019;40(8): 577-591. https://doi.org/10.1016/j.tips.2019.05.005.

[36]. Stavros P. Kalafatis, Markos H. Tsogas, Charles Blankson. Positioning strategies in business markets. Journal of Business & Industrial Marketing, 2000; 15(6); 416-437. https://doi.org/10.1108/08858620010349501.

[37]. Anne Maarit Jalkala, Joona Kera¨nen. Brand positioning strategies for industrial firms providing customer solutions. Journal of Business and Industrial Marketing, 2014;29(3) :253–264. DOI 10.1108/JBIM-10-2011-0138.

[38]. Min Ding, Jehoshua Eliashberg, Stefan Stremersch. Innovation and Marketing in the Pharmaceutical Industry,2014; Volume 20. ISBN : 978-1-4614-7800-3.

[39]. Wenyu Dou, Kai H. Lim, Chenting Su, Nan Zhou, et al. Brand Positioning Strategy Using Search Engine Marketing. MIS Quarterly, 2010; 34(2):261-279. DOI:10.2307/20721427.

[40]. Grzegorz MACIEJEWSKI, Mirosâawa MALINOWSKA. Use Of Big Data On The Food Market Areas, Applications, Examples. 25th International Scientific Conference PGV Network At: 12-13 September 2019 Bucharest, Romania

[41]. Koohy, H. The rise and fall of machine learning methods in biomedical research. 2017. F1000 Res. 6 http://dx.doi.org/10.12688/f1000research.13016.2

[42]. Myers, Raymond H. and Douglas C. Montgomery. Response Surface Methodology: Process and Product Optimization Using Designed Experiments, 1995. DOI: 10.2307/1270613.

[43]. Zawbaa HM, Szlęk J, Grosan C, Jachowicz R, Mendyk A. Computational Intelligence Modeling of the Macromolecules Release from PLGA Microspheres—Focus on Feature Selection. PLoS ONE, 2016; 11(6): e0157610. https://doi.org/10.1371/journal.pone.0157610.

[44]. Lima AN, Philot EA, Trossini GH, Scott LP, Maltarollo VG, Honorio KM. Use of machine learning approaches for novel drug discovery. Expert Opin Drug Discovery, 2016;11(3):225-239. doi: 10.1517/17460441.2016.1146250.

[45]. Park JS, Kim JR. Non-compartmental data analysis using SimBiology and MATLAB. Translational and Clinical Pharmacology, 2019 ;27(3):89-91. doi: 10.12793/tcp.2019.27.3.89.

[46]. Martin E, Mukherjee P, Sullivan D, Jansen J. Profile-QSAR: a novel meta-QSAR method that combines activities across the kinase family to accurately predict affinity, selectivity, and cellular activity. Journal of Chemical Information and Modeling, 2011;51(8):1942-56. doi: 10.1021/ci1005004.

[47]. Merget B, Turk S, Eid S, Rippmann F, Fulle S. Profiling Prediction of Kinase Inhibitors: Toward the Virtual Assay. Journal of Medicinal Chemistry, 2017;60(1):474-485. doi: 10.1021/acs.jmedchem.6b01611.

[48]. Chan HCS, Shan H, Dahoun T, Vogel H, Yuan S. Advancing Drug Discovery via Artificial Intelligence. Trends in Pharmacological Sciences, 2019;40(8):592-604. doi: 10.1016/j.tips.2019.06.004.

[49]. Reker D. Practical considerations for active machine learning in drug discovery. Drug Discovery Today: Technologies, 2019;32-33:73-79. doi: 10.1016/j.ddtec.2020.06.001.