Health Tech Asmnt Act. 7(4).

Review Article

Application of Artificial Intelligence in the Pharmaceutical Industry

Tohid Nazari[1], Elmira Ezzati[1], Hamid Reza Rasekh[1], Zahra Gharib-Naseri[1]*

[1]Department of Pharmacoeconomics and Pharma Management, School of Pharmacy, Shahid Beheshti University of Medical Sciences, Tehran, Iran

*Corresponding Author: Department of Pharmacoeconomics and Pharma Management, School of Pharmacy, Shahid Beheshti University of Medical Sciences, Tehran, Iran. Email: gharibnaseri_z@sbmu.ac.ir

Received 2023 September 17; Accepted 2023 November 18.

Abstract

Background: The potentials of artificial intelligence (AI) have permeated all industries and fields, and the advantages of AI are extensively employed. This technology offers a wide range of benefits in the pharmaceutical industry, including reducing human interventions and increasing the speed and accuracy of tasks. This can expedite time-consuming activities, such as drug discovery, production, clinical trials, research and development, and ultimately, determining a drug's position in target markets.

Methods: A comprehensive scope review was performed in this descriptive, applied study on the applications of AI in the pharmaceutical industry in Iran. Relevant data were meticulously gathered and extracted from diverse sources, including various search engines, key databases, such as Medline, PubMed, Elsevier, and the Iranian Center for Scientific Information and Documentation, and information databases, reference books, and reports from the World Health Organization. These results represent our research on key themes, including AI, the pharmaceutical industry, drug production, innovation, and evolution. Our main focus lies on the application of AI in the manufacturing part of the pharmaceutical industry, with a deliberate decision not to delve into the technical aspects. This approach allowed us to prioritize a comprehensive understanding of the practical implications and advancements in the manufacturing processes facilitated by artificial intelligence.

Results: The retrieved studies showed that AI has the potential to enhance crucial processes in pharmaceutical companies across various dimensions. These potential capabilities are observed in areas such as quality control, human resource management, research and development, finance, supply chain management, logistics, data management, operations management, customer relationship management, and commerce, which are further discussed.

Conclusions: Pharmaceutical companies can utilize the tools provided by AI in various value-creating processes to enhance their efficiency and effectiveness. This requires the adoption and integration of this innovative technology at various levels of organizational planning so that these companies can harness the greater potential it offers with appropriate investments.

Keywords: Artificial Intelligence; Pharmaceutical Industry; Drug Production; Innovation; Evolution

1. Introduction

The use of artificial intelligence (AI) has permeated all industries and domains, and its benefits are widely embraced. It is believed that AI will bring about fundamental changes in the world in the not-so-distant future (1).

Artificial intelligence encompasses various branches. The first branch is machine learning. Machine learning-based systems can learn different patterns of a process. One of the applications of this branch is predicting the final product and efficiency of reactions using influential variables in this process. The second branch pertains to artificial neural networks. Systems based on artificial neural networks consist of a multitude of neural units that process information collectively. In the absence of one unit, others can compensate to a significant extent. Artificial neural network systems have been used, for example, to determine the mechanisms of action of anticancer drugs. The third branch involves systems commonly known as machine vision. These systems, much like the sensory organs of the human body, can process environmental information. One of their applications is monitoring the pharmaceutical packaging process. The fourth branch comprises expert systems. These systems, equipped with predefined assumptions and rules, can reason and reach a conclusion using a set of premises. Expert systems have been used in diagnosis, utilizing patient signs and symptoms. The fifth branch is natural language processing. This branch is dedicated to designing systems that understand and process human spoken and written languages. The use of systems capable of correcting sentence structure is one example of this field.

The final branch is robotics, which is an interdisciplinary field combining various sciences, such as computer engineering, mechanical engineering, and electronics. This field is primarily involved in the design of various robots, and extensive research has been conducted to utilize this field in the design of medical equipment and intelligent artificial body parts (2, 3).

Pharmaceuticals hold a unique and strategic position in the health care system. In the pharmaceutical industry, AI reduces human interventions and increases the speed and accuracy of processes, thereby expediting time-consuming activities, such as research and development, production, clinical trials, postmarket studies, and, ultimately, market research in target markets. The pharmaceutical industry encompasses a collection of companies and economic enterprises involved in the production of pharmaceutical raw materials, the manufacturing of final pharmaceutical products, and pharmaceutical packaging (4).

From an international perspective, pharmaceutical production is categorized into 3 levels. At the first level, factories produce active pharmaceutical ingredients (APIs), intermediates, and excipients. Industrialized countries and large emerging economies, such as China and India, primarily manufacture products falling into this category. At the second level, production typically involves mixing raw materials and creating various pharmaceutical formulations. Most factories in countries with moderate income levels operate at this level. At the third level, the focus is on packaging the manufactured products or performing very small-scale production. This level is more common in countries with lower incomes (5) . However, most pharmaceutical factories in Iran operate at the second production level. The pharmaceutical industry in developing countries is of great importance due to its significant role in providing access to medications in terms of availability and affordability. Therefore, supporting the sustainable efficiency of the pharmaceutical industry is essential (6).

According to the results of a report, it is estimated that about 60% of pharmaceutical companies worldwide are planning to employ AI. Pfizer, Sanofi, GSK, and AstraZeneca are major pharmaceutical companies that have invested the most in AI, respectively (7). Industry 4.0 is unlikely to yield immediate returns like any other investment. However, the adoption of this new technology should be based on long-term value, offering a new production pattern that provides better control, error reduction, improved responsiveness, and drug shortage mitigation (8). The AI market in the healthcare system increased from $200 million in 2015 to $700 million in 2018, and it is predicted to reach $5 billion by 2024. The pharmaceutical and medical sectors are expected to grow by 40% from 2017 to 2024, primarily due to the utilization of AI (9).

2. Method

A comprehensive scope review was employed in this descriptive, applied study on the applications of AI in the pharmaceutical industry in Iran. Up to September 2023, relevant data were meticulously gathered and extracted from diverse sources, including various search engines, key databases, such as Medline, PubMed, Elsevier, and the Iranian Center for Scientific Information and Documentation, and information databases, reference books, and reports from the World Health Organization. These results represent our research on key themes, including AI, the pharmaceutical industry, drug production, innovation, and evolution. The databases were searched up to September 2023.

Our primary focus was on the use of AI in the manufacturing part of the pharmaceutical industry, with a deliberate decision not to examine the technical aspects. This approach lets us prioritize a comprehensive understanding of the practical implications and advancements in the manufacturing processes facilitated by AI.

3. Results

The studies showed that AI has the potential to enhance critical processes in pharmaceutical companies across various dimensions. These potential capabilities are observed in areas such as quality control, human resource management, research and development, financial operations, supply chain management, logistics, data management, operations management, customer relationship management, and commerce. These areas are discussed in more detail below.

3.1. Quality Control

The next generation of pharmaceutical manufacturing, utilizing integrated and autonomous production systems operating without human intervention, is defined as Industry 4.0. This advanced digital age includes the Internet of Things (IoT), AI, robotics, and complex computing, from data collection to the highest level of digital maturity. Currently, the primary challenge for drug manufacturers, which is the control of production processes, can be effectively addressed by Industry 4.0. While most pharmaceutical manufacturers have readily used basic tools such as quality by design (QbD) for production risk management, fewer are inclined to make further advancements with advanced technologies to support smart manufacturing (8). The QbD emphasizes product and process understanding and control based on science and quality risk management (QRM) (10).

Various computer programs can assist in solving problems in formulation design, such as stability, dissolution rate, and porosity (9). Utilizing state-of-the-art AI algorithms can enhance product quality and ensure a safer production process (11). Quality risk management is employed to identify and address risks in various areas. It involves a collaborative effort by a group of experts who examine the product and its manufacturing process. The first step is assessing the risks by considering their likeli-

hood, detectability, and potential impact. Subsequently, these risks are analyzed and evaluated based on specific guidelines or standards. Using manual methods for sampling and testing materials is not suitable for continuous production. Continuous manufacturing is superior to batch manufacturing because it provides greater control over every stage of drug production, down to a very small-scale level known as micro-level process control (12).

Currently, tools such as fault tree analysis (FTA) and failure modes and effects analysis (FMEA) are used for precise assessments. These methods help measure potential scenarios that might go wrong during the production processes. Additionally, there are various computer programs available that can simulate fluid systems, powder mixing, particle systems, and pharmaceutical modeling (4).

3.2. Human Resource Management

Certainly, new requirements are essential for future workforce training, implying a need for robust training programs (8). The lack of talent management and appropriate human resource management methods can lead to challenges such as increased costs for hiring new employees, a rise in their salaries, escalation of training expenses, and harming the organization's reputation. These factors can impact customers, business partners, and employees' perceptions of the organization. The development of information technology (IT) systems has facilitated aspects like recruiting new employees, financial resource management, advertising, staff management, and fostering positive internal relationships.

These tasks have improved since the implementation of IT systems. The use of AI has a positive impact on how employers are perceived by others. Furthermore, the adoption of AI has a significant positive effect on employee retention (13), can help select the most suitable individuals for medical studies, and can provide a means for compensating and motivating employees. This tool assists managers in identifying whether someone is in an inappropriate job position or is receiving excessive income. In the future, conversational robots can conduct interviews and evaluate how well a person fits an occupational role (14).

3.3. Research and Development

Discovering and developing a new drug can be a lengthy and costly process. It typically takes more than 10 years and has an average cost of approximately $2.8 billion. However, out of every 10 therapeutic molecules, 9 do not successfully pass Phase II clinical trials and regulatory approval (15, 16).

Artificial intelligence can help discover new applications for existing drugs. Using a drug that already exists qualifies it for Phase II clinical trials, resulting in cost savings. Repurposing an existing drug costs around $8.4 million, while launching an entirely new drug costs about $41.3 million. Clinical trials are conducted to ensure a drug's safety and suitability for a specific disease, a process that takes approximately 6 - 7 years and involves significant costs (9). Although we currently have the initial knowledge and tools for developing new drugs, we still need to do more work in bringing together the fields of pharmaceutical sciences and engineering. This will create a new field called pharmaceutical engineering (4).

3.4. Financial Operations

New technologies can assist employees in financial sectors and provide them with more time to generate new ideas. However, individuals who have been interviewed and are currently working in pharmaceutical companies believe that AI will not have a significant impact on financial matters and business operations control in the next decade (14). Nevertheless, when it comes to capital return compared to the level of risk, the pharmaceutical industry does not perform as well as other industries like the automotive sector. This is probably because the pharmaceutical industry has greater hazards and risks associated with its business operations (17).

3.5. Supply Chain Management

The primary task of inventory management in any industry is to enhance warehouse operations' efficiency and reduce the costs of transporting goods. It is possible for robots and AI to be employed to assist in handling orders in warehouses, potentially reducing the need for labor in this regard (14).

Currently, APIs are produced in large batches and supplied to pharmaceutical manufacturers, where they are mass-produced in centralized manufacturing facilities. The new paradigm could change how pharmaceuticals are produced, distributed, and ultimately delivered to patients. The new drug production model will no longer depend on the supply chain (10). This change can have positive outcomes, such as having fewer unused items in stock, faster delivery times for patients in urgent need of medication, and better ways to ensure the quality of drugs. Changes will be made in how drugs are manufactured. Instead of large factories in developed countries producing popular drugs, there will be smaller production sites around the world manufacturing various drugs.

With drug printers, pharmaceutical companies will have the capability to customize which medications are combined in a tablet or liquid exclusively for the patient. These new three-dimensional (3D) printing methods can bring drugs closer to people's living areas instead of distant locations like large factories. This reduces costs by approximately 30%, consumes about 25% less space, and reduces operational expenses by around 30%. Furthermore, patients will not face difficulties in accessing their medications due to reduced waiting times and fewer supply chain problems. However, there are limitations

as well. For instance, rectifying errors or interruptions in the middle of ongoing processes can be challenging. To transition towards continuous manufacturing, we need to integrate various approaches from different fields and enhance communication between different stages of the supply chain. To eliminate barriers between different departments within a company, we require leaders who are knowledgeable in both technical matters and the functioning of other business units (12).

3.6. Laws and Regulations

Legal barriers must be addressed to make Industry 4.0 a reality in the pharmaceutical sector. The industrial control in which some pharmaceutical companies adhere to the principles of Industry 2.0 while others are moving towards Industry 4.0 will be a key challenge. The pace of this transition will vary from one manufacturer to another (8). So far, no pharmaceuticals have been completely manufactured using AI, and adherence to the stringent regulations required is crucial to move from one stage to another in the pharmaceutical industry (14).

All stakeholders, especially the public, are concerned about the ethical and legal implications of using AI in the healthcare system, particularly in the pharmaceutical sector. One concern is that AI systems may have biases in their algorithms and data. Biases can involve unfair treatment of specific groups of people based on race or other factors. Another challenge is related to individuals' privacy; it involves who can access patients' information and how it is securely maintained. There is also concern about safety and who will be responsible if a problem arises in an AI system during a medical procedure (18). Therefore, there is a need for automated control systems that are regulated by oversight organizations, such as the Food and Drug Administration (FDA), and collaboration between various industries and stakeholders to ensure that automated control systems function effectively and safely (12).

3.7. Data Management

The pharmaceutical industry is also based on data collection and analysis. People often do not realize the extensive effort that goes into gathering and organizing data from various sources to properly analyze them. Trust is essential in data science and can be built upon good education, high standards, and reliable data. We must also understand that not everything may be perfect from the beginning. We should remain open to new data-handling solutions and incomplete insights. However, if people had not used the initial versions, more advanced versions would have never been developed (19).

Artificial intelligence faces significant data-related challenges that make the work difficult. These challenges include dealing with vast amounts of data, continually growing data, data heterogeneity, and data uncertainty. Drug development in pharmaceutical companies often involves massive datasets, such as millions of compounds. IBM's Watson is a tool that employs AI technology to assist doctors in studying a patient's medical information using a large database, helping them suggest cancer treatment options. It can detect breast cancer in only 60 seconds (20).

Despite the rapid advancements in AI algorithms and machine learning used in the pharmaceutical industry, there are still many challenges regarding the application of these technologies in drug discovery and the pharmaceutical industry as a whole. This challenge arises because datasets can be diverse and encompass various types of data, including raw, processed, and big data. Proper data organization is crucial before commencing the drug discovery process, as poorly structured data will yield inaccurate results from machine learning algorithms (11). Big data refers to extremely large and complex datasets that cannot be readily analyzed using conventional software, tools, and techniques. Companies often need to invest significant time and effort into cleaning the data before they can effectively utilize it. In fact, approximately 80% of the time is spent on data cleaning, with only about 20% allocated to applying algorithms. The IT sector within companies has become more critical, and IT managers must continuously enhance their skills to help the company's technological systems perform effectively (14).

Big data has 3 main characteristics: volume, velocity, and variety. Volume refers to the large amount of data being generated. Velocity indicates the speed at which this data is produced. Variety points to the different types of data within datasets. Advances in AI have simplified the process of analyzing large datasets. When AI is exposed to more information, it becomes smarter and continuously enhances the pharmaceutical industry. Artificial intelligence can be used in health care for tasks such as managing medical records and other data, performing repetitive tasks, designing treatments, providing digital consultations, offering virtual nursing services, managing medications, discovering new drugs, implementing precision medicine, monitoring healthcare, and analyzing healthcare systems (21).

3.8. Operations Management

Artificial intelligence language models have various applications in pharmaceutical sciences. Scientists and experts should thoroughly examine the results of these models and ensure the accuracy of the models and the absence of any bias. They should also explain any potential priorities or problems with AI models and recognize the importance of human knowledge and reasoning in research (22).

Computational intelligence techniques can be useful to study how to improve drugs (23). The drug repurposing process, also known as drug repositioning, involves identifying new and innovative therapeutic applications for approved drugs. For example, metformin, typically used

for managing type 2 diabetes, may help increase the lifespan. Companies can utilize AI programs to create production plans using internal and external data. These recommendations impact finding system problems and flaws, predicting equipment usage, and improving equipment usage and maintenance under ideal conditions (14)

3.9. Customer Relationship Management

Chatbots have been around for a while and work well. Many people are aware that when they talk to chatbots, they are essentially communicating with a computer. This can make them feel that the company does not truly value them and disregards their concerns. Chatbots should only be used when the recipient responds well to them and human support is available. An organization should use AI to assist its sales team, but if it creates a gap between the company and its customers, the plan may fail (24). Artificial intelligence helps users customize their tasks using specific details, such as company location, the number of employees, the work they engage in, and the time spent on the supplier's website. This information creates profiles of customers who operate in similar ways. Subsequently, the AI software suggests ways for them to collaborate. Furthermore, specialized information aids managers in gaining a more effective understanding of the decision-making process concerning a customer's purchase or a specific company (14).

3.10. Commerce

The use of the latest AI algorithms can expedite products' entry into the market (11). E-VAI is an intelligent computer program that aids marketing managers in the pharmaceutical industry. It utilizes advanced technology and a user-friendly interface to analyze competitors, key individuals involved, and current market share. With this information, it predicts the factors driving sales and assists managers in deciding where to invest resources to gain a larger market share, improve sales, and prepare for future changes (9).

Seven important factors enable the use of AI and machine learning in healthcare. The first point is that a patient's medical history is transformed into digital files. Secondly, these files can then be easily shared with others. The third advantage is that digital mapping is more robust and reliable than human intervention. The fourth advantage is AI's ability to improve clinical work and record patients accurately. The fifth advantage is AI's ability to provide theories or ideas in research. The sixth factor is the time when people share information and learn many things. The seventh factor is the time when AI can even improve situations with a lot of data. Machine learning and AI assist life sciences sales, marketing, and branding teams in creating more profitable and effective business strategies based on AI insights. It also helps improve product value, allocate resources efficiently, increase market share, and provide appropriate sales and marketing information (24). Large pharmaceutical companies use AI to change the way they manufacture, sell, advertise, and analyze their products. Medium-sized companies are positioned in the middle and adapt their business processes based on their expertise (14).

4. Conclusion was supposed to come after discussion sector.

The potential applications of AI in the pharmaceutical industry are extensive and can significantly benefit pharmacists in the future. In the first phase, the use of AI in drug management can considerably enhance the accuracy and safety of drug distribution. Pharmacists can utilize AI-equipped systems to provide personalized drug recommendations and monitor patient adherence to medications. In the second phase, the use of AI in drug development can expedite the drug discovery process and assist pharmacists in identifying potential therapeutic goals more effectively. This can help pharmacists produce new drugs more quickly and at a lower cost, leading to reduced health care expenses and increased treatment efficacy (25).

The results of the current study highlighted the potential effectiveness of AI in various dimensions of the pharmaceutical industry, including quality control, human resource management, research and development, finance, supply chain and logistics management, data management, operations management, customer relationship management, and commerce. Previously, a review study by Donepudi (2018) discussed the potential effectiveness of AI in resource and time management, predictive analytics, and data management. The mentioned predictive analytics in the previous study also overlaps with risk management (a subset of quality control), as it includes the prediction of harm levels (26).

Mishra (2018) also stated that the primary advantage of AI is its ability to reduce the time required for drug development, consequently lowering the costs associated with drug development, increasing return on investment, and potentially reducing the costs for the end consumer. These aspects have also been explicitly mentioned in the dimensions of research and development and finance of the present study (27).

A review study by Khan et al. (2023) highlighted the potential of AI in improving drug management, patient care, and treatment effectiveness (28). In the present study, the potential role of AI in enhancing various dimensions of drug management was enumerated, but the primary focus of the present study was not on health care effectiveness. Additionally, Kulkov (2021) expressed the significant potential role of AI in transforming data management, human resource management, and research and development in small pharmaceutical companies, as well as the financial and commercial transformation of large pharmaceutical companies. All of these aspects were also discussed in the present study, but there was

not much emphasis on distinguishing the changes between large and small pharmaceutical companies (14).

Studies investigating the changes in the pharmaceutical industry in the realm of AI have predominantly been conducted using library methods, which further underscores the significance of a field study by Khatib and Ahmed (2020). In this study, which focused on robotic pharmacies, reduced costs and error rates, shorter patient waiting times, and enhanced service efficiency were observed in robotic pharmacies compared to traditional pharmacies. However, note that the above study, unlike the present one, primarily concentrated on a small segment of the pharmaceutical industry. Nevertheless, the results of this study align with the potential roles enumerated for AI in financial and customer relationship management dimensions (29).

The findings of the present study also addressed the legal dimensions of AI-driven development of the pharmaceutical industry. This area should be a focus for government attention and investment, as legislation in this domain appears to progress more slowly than AI development itself. For instance, the first AI law has recently been debated in the European Parliament, and clear legislation in this regard is yet to be defined in many countries (30, 31).

According to previous studies, 72% of pharmaceutical companies acknowledge the necessity of incorporating AI in their future strategies (32). In light of the results of the present study, each dimension, including quality control, human resource management, research and development, finance, supply chain management, logistics, data management, operations management, customer relationship management, and commerce, can be a potential target for pharmaceutical companies' investment in AI utilization. Nevertheless, as per the findings of Kulkov (2021), the investment trends of pharmaceutical companies in developing various AI dimensions should be tailored to the company's specialization and size, and a one-size-fits-all approach cannot be recommended for all pharmaceutical firms (14). The future working environment of pharmaceutical companies utilizing AI can be envisioned as close collaboration between individuals well-versed in algorithms and AI with pharmaceutical chemists. The former will be capable of training machines and configuring algorithms, while the latter can assist in analyzing vast datasets (33).

However, there is currently no suitable IT system in place, as the existing IT programs and frameworks have not been tailored for AI. Certainly, pharmaceutical companies will need to allocate significant resources to enhance their IT systems. Health and medical care data are private and accessible only through authorized channels. On the other hand, pharmaceutical companies are generally resistant to change (20). Another major challenge is data sharing. Continuous education with new data from medical research is essential to improving the performance of AI systems. After the systems have learned from all the old data, it is necessary to feed more data into the systems to make them better. Another problem with using AI is ensuring its transparency and alignment with what the general public desires while encouraging the generation of new ideas in this field (24).

4.1. Limitations and Recommendations

In previous studies on the potential efficiency of AI in the pharmaceutical industry, data collection was primarily conducted using a library method. However, the use of this framework in the real world may encounter new, undefined challenges. Therefore, future studies must collect data in the field whenever possible and test the hypotheses in the real world. The scarcity of previous studies presented a new challenge in data collection, highlighting the need for further research in this emerging field. Due to the absence of laws and regulations regarding the use of AI in Iran, it is recommended that legislative bodies become involved in this area.

Conclusion:

Conclusions: Pharmaceutical companies can utilize the tools provided by AI in various value-creating processes to enhance their efficiencyand effectiveness. This requires the adoption and integration of this innovative technology at various levels of organizational planning sothat these companies can harness the greater potential it offers with appropriate investments.

Author Contribution: H.R developed the theory. T.N , E.E. and Z.G. carried out the study and drafted the manuscript. All authors discussed the results and contributed to the final manuscript.

Conflict of Interest: Authors have no conflict of interest associated with this publication to declare.

funding: The authors received no financial support for the research, authorship or publication of this article.

References

1. Ertel W. *Introduction to artificial intelligence*. Springer International Publishing; 2018.
2. Malik H, Srivastava S, Sood YR, Ahmad A. *Applications of artificial intelligence techniques in engineering*. Springer; 2018.
3. Sahu A, Mishra J, Kushwaha N. Artificial intelligence (AI) in drugs and pharmaceuticals. *Comb Chem High Throughput Screen.* 2022;**25**(11):1818-37. [PubMed ID:34875986]. https://doi.org/10.2174/1386207325666211207153943.
4. Rantanen J, Khinast J. The future of pharmaceutical manufacturing sciences. *J Pharm Sci.* 2015;**104**(11):3612-38. [PubMed ID:26280993]. [PubMed Central ID:PMC4973848]. https://doi.org/10.1002/jps.24594.
5. Bennett S, Jonathan DQ, Valasquez G. *Public-private roles in the pharmaceutical sector : implications for equitable access and rational drug use*. Geneva: World Health Organization; 1997.
6. Yousefi N, Mehralian G, Peiravian F, Noee F. Generic substitution policy implementation: A pharmacists' perspective survey. *J Generic Med.* 2015;**12**(1):17-25. https://doi.org/10.1177/1741134315608908.
7. Research P. "Ai in pharmaceutical market size, share, report 2021-2030 2022. Available from: https://www.precedenceresearch.com/ai-in-pharmaceutical-market.
8. Arden NS, Fisher AC, Tyner K, Yu LX, Lee SL, Kopcha M. Industry 4.0 for pharmaceutical manufacturing: Preparing for the smart

factories of the future. *Int J Pharm.* 2021;**602**:120554. [PubMed ID:33794326]. https://doi.org/10.1016/j.ijpharm.2021.120554.
9. Paul D, Sanap G, Shenoy S, Kalyane D, Kalia K, Tekade RK. Artificial intelligence in drug discovery and development. *Drug Discov Today.* 2021;**26**(1):80-93. [PubMed ID:33099022]. [PubMed Central ID:PMC7577280]. https://doi.org/10.1016/j.drudis.2020.10.010.
10. Miller JA, Fredrickson ME, Greene JM, Jay M, Oyewumi MO. Reimagining drug manufacturing paradigm in today's pharmacy landscape. *J Am Pharm Assoc.* 2022;**62**(6):1761-4. [PubMed ID:36115758]. [PubMed Central ID:PMC9425710]. https://doi.org/10.1016/j.japh.2022.08.024.
11. Sarkar C, Das B, Rawat VS, Wahlang JB, Nongpiur A, Tiewsoh I, et al. Artificial intelligence and machine learning technology driven modern drug discovery and development. *Int J Mol Sci.* 2023;**24**(3). [PubMed ID:36768346]. [PubMed Central ID:PMC9916967]. https://doi.org/10.3390/ijms24032026.
12. Srai JS, Badman C, Krumme M, Futran M, Johnston C. Future supply chains enabled by continuous processing—opportunities challenges may 20–21 2014 continuous manufacturing symposium. *J Pharm Sci.* 2015;**104**(3):840-9. https://doi.org/10.1002/jps.24343.
13. Kot S, Hussain HI, Bilan S, Haseeb M, Mihardjo LWW. The role of artificial intelligence recruitment and quality to explain the phenomenon of employer reputation. *J Bus Econ Manag.* 2021;**22**(4):867-83. https://doi.org/10.3846/jbem.2021.14606.
14. Kulkov I. The role of artificial intelligence in business transformation: A case of pharmaceutical companies. *Technol Soc.* 2021;**66**. https://doi.org/10.1016/j.techsoc.2021.101629.
15. Alvarez-Machancoses O, Fernandez-Martinez JL. Using artificial intelligence methods to speed up drug discovery. *Expert Opin Drug Discov.* 2019;**14**(8):769-77. [PubMed ID:31140873]. https://doi.org/10.1080/17460441.2019.1621284.
16. Fleming N. How artificial intelligence is changing drug discovery. *Nature.* 2018;**557**(7707):S55-S7. [PubMed ID:29849160]. https://doi.org/10.1038/d41586-018-05267-x.
17. Abramavicius S, Stundziene A, Korsakova L, Venslauskas M, Stankevicius E. Stock price reaction to the drug development setbacks in the pharmaceutical industry. *J Fac Pharm Tehran Univ Med Sci.* 2021;**29**(1):1-11. [PubMed ID:33539000]. [PubMed Central ID:PMC8149546]. https://doi.org/10.1007/s40199-020-00349-6.
18. Reddy S, Allan S, Coghlan S, Cooper P. A governance model for the application of AI in health care. *J Am Med Inform Assoc.* 2020;**27**(3):491-7. [PubMed ID:31682262]. [PubMed Central ID:PMC7647243]. https://doi.org/10.1093/jamia/ocz192.
19. Finelli LA, Narasimhan V. Leading a digital transformation in the pharmaceutical industry: Reimagining the way we work in global drug development. *Clin Pharmacol Ther.* 2020;**108**(4):756-61. [PubMed ID:32294230]. [PubMed Central ID:PMC7540662]. https://doi.org/10.1002/cpt.1850.
20. Patel H. A review: Future aspects of artificial intelligence big data and robotics in pharmaceutical industry. 2021.
21. Gupta R, Srivastava D, Sahu M, Tiwari S, Ambasta RK, Kumar P. Artificial intelligence to deep learning: machine intelligence approach for drug discovery. *Mol Divers.* 2021;**25**(3):1315-60. [PubMed ID:33844136]. [PubMed Central ID:PMC8040371]. https://doi.org/10.1007/s11030-021-10217-3.
22. Davies NM. Adapting artificial intelligence into the evolution of pharmaceutical sciences and publishing: Technological darwinism. *J Pharm Pharm Sci.* 2023;**26**:11349. [PubMed ID:37034476]. [PubMed Central ID:PMC10075305]. https://doi.org/10.3389/jpps.2023.11349.
23. Lopez-Rubio E, Elizondo DA, Grootveld M, Jerez JM, Luque-Baena RM. Computational intelligence techniques in medicine. *Comput Math Methods Med.* 2015;**2015**:196976. [PubMed ID:25834633]. [PubMed Central ID:PMC4365332]. https://doi.org/10.1155/2015/196976.
24. Khanna V, Ahuja R, Popli H. Role of artificial intelligence in pharmaceutical marketing: a comprehensive review. *J Adv Sci Res.* 2020;**11**(03):54-61.
25. Flynn A. Using artificial intelligence in health-system pharmacy practice: Finding new patterns that matter. *Am J Health Syst Pharm.* 2019;**76**(9):622-7. [PubMed ID:31361834]. https://doi.org/10.1093/ajhp/zxz018.
26. Donepudi PK. Ai and machine learning in retail pharmacy: Systematic review of related literature. *ABC J Adv Res.* 2018;**7**(2):109-12. https://doi.org/10.18034/abcjar.v7i2.514.
27. Mishra V. Artificial intelligence: The beginning of a new era in pharmacy profession. *Asian J Pharm.* 2018;**12**(02).
28. Khan O, Parvez M, Kumari P, Parvez S, Ahmad S. The future of pharmacy: How AI is revolutionizing the industry. *Intel Pharm.* 2023;**1**(1):32-40. https://doi.org/10.1016/j.ipha.2023.04.008.
29. Khatib MME, Ahmed G. Robotic pharmacies potential and limitations of artificial intelligence: a case study. *Int J Bus Innov Res.* 2020;**23**(3). https://doi.org/10.1504/ijbir.2020.110972.
30. Del Castillo AP. A law on robotics and artificial intelligence in the EU? *Eu Trade Union Inst.* 2020.
31. Siegmann C, Anderljung M. The brussels effect and artificial intelligence: How eu regulation will impact the global ai market. *Cornell Univ.* 2022. https://doi.org/10.33774/apsa-2022-vxtsl.
32. Raza MA, Aziz S, Noreen M, Saeed A, Anjum I, Ahmed M, Raza SM. Artificial intelligence (AI) in pharmacy: An overview of innovations. *Innov Pharm.* 2022;**13**(2). [PubMed ID:36654703]. [PubMed Central ID:PMC9836757]. https://doi.org/10.24926/iip.v13i2.4839.
33. Mak KK, Pichika MR. Artificial intelligence in drug development: present status and future prospects. *Drug Discov Today.* 2019;**24**(3):773-80. [PubMed ID:30472429]. https://doi.org/10.1016/j.drudis.2018.11.014.