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Review Article

Artificial Intelligence in Pharmaceuticals: Exploring Applications and Legal Challenges

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ABSTRACT

Background and Objectives: The pharmaceutical sciences have the potential to benefit significantly from the advancements in artificial intelligence (AI). One of the primary areas where AI can prove invaluable is the discovery and development of new drugs. Compared to traditional methods, with the help of AI algorithms, vast amounts of data can be analyzed more efficiently, leading to the rapid identification of potential drug candidates. AI has the potential to expedite the drug discovery process, thereby leading to the development of new treatments for various diseases. This article delves into the manifold applications of AI in the pharmaceutical industry and the legal challenges that come with it.

Methods: This study conducted a thorough search on the PubMed, Scopus, and Google Scholar databases using the following keywords: “Artificial intelligence”, “neural network”, “pharmacy”, “pharmaceutical”, “drug discovery”, “legal”, and “ethical”. In addition, we obtained further references by cross-referencing from essential articles. This article comprehensively overviews how AI is applied in the pharmaceutical industry and highlights the critical legal and ethical challenges.

Results: AI can assist in personalized medicine by analyzing patient data and providing tailored treatment plans. By considering individual patient characteristics, such as genetics and medical history, AI algorithms can help healthcare professionals make more informed decisions about which treatments will most likely be effective for each patient. In addition to drug discovery and personalized medicine, AI can also enhance the efficiency of pharmaceutical manufacturing processes. AI-powered systems can monitor and optimize production lines, ensuring that quality standards are met while reducing the risks of errors or deviations. Additionally, AI can be an essential tool in pharmacovigilance through real-world data analysis, which can detect adverse drug reactions and other safety concerns. This approach can aid regulatory authorities and pharmaceutical companies identify and address potential medication risks more effectively.

Conclusion: AI application in the pharmaceutical sciences has marked potential for improving drug discovery, clinical trials, personalized medicine, manufacturing processes, and pharmacovigilance. By using the power of AI, the industry can boost efficiency, cut costs, and ultimately deliver better healthcare outcomes for patients.

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Introduction

The pharmaceutical industry has transformed significantly thanks to advanced technologies like artificial intelligence (AI). AI has streamlined drug discovery and development, making it more efficient and cost-effective. As the demand for innovative drugs increases, AI has become a game-changer.

AI is a branch of computer science that creates machines that mimic human intelligence and carry out tasks that typically require human-like intelligence. These tasks include problem-solving, learning, and decision-making. In the pharmaceutical industry, AI analyzes vast amounts of data, detects patterns, and predicts outcomes based on the information. This results in faster and more accurate results [1].

AI has become essential in pharmaceutical science, particularly drug discovery. The traditional drug discovery process is time-consuming and expensive; however, AI has revolutionized this process by creating intelligent machines that can perform tasks requiring human-like intelligence. These tasks include problem-solving, learning, and decision-making. In the pharmaceutical industry, AI analyzes vast datasets, detects patterns, and screens millions of compounds to identify potential drug candidates, leading to faster and more accurate outcomes based on data [2]. However, AI algorithms can analyze vast amounts of data from various sources, including clinical trials, scientific literature, and genetic databases, to identify potential drug candidates, thus significantly accelerating the process [1].

AI can also optimize drug design by analyzing the chemical structure of compounds and predicting their properties. This can help identify potential modifications to improve their efficacy and safety, considerably reducing the time and cost associated with traditional drug design methods [3].

Moreover, AI plays a crucial role in clinical trials. Recruiting patients for clinical trials can be challenging and time-consuming. Still, AI algorithms can identify potential patients based on their medical history and other criteria, making the recruitment process faster and more efficient [1, 4].

AI can also analyze large datasets from clinical trials, identify patterns, and predict outcomes. This helps researchers to identify potential safety issues and optimize dosing regimens, leading to better patient outcomes [5].

Apart from drug discovery and development, AI is also used in other areas of pharmaceutical science. For example, AI algorithms can optimize drug manufacturing processes, reducing costs and improving efficiency. Additionally, AI can monitor drug safety post-approval, identifying potential adverse events and improving patient outcomes [1, 2].

Nevertheless, some challenges need to be addressed to benefit from AI in pharmaceutical science. For instance, the quality of data used is crucial for accurate predictions. Also, regulatory oversight is necessary to ensure that AI algorithms are safe and effective. Regulatory bodies, such as the Food and Drug Administration (FDA), are already working to develop guidelines for using AI in pharmaceutical science [4].

The role of artificial intelligence in the pharmaceutical industry

Drug discovery

The impact of AI has been observed across various industries, including the pharmaceutical industry. In recent years, AI has gained momentum in the pharmaceutical industry and holds the potential to transform the drug development, testing, and marketing process [6].

Drug discovery is one of the pharmaceutical industry's most significant applications of AI. Discovering a new drug can take years and cost billions of dollars. AI can help streamline this process by analyzing vast amounts of data and predicting which compounds will likely be effective. This can help researchers narrow their focus and identify potential drug candidates more quickly [7, 8].

AI has revolutionized numerous industries, and drug discovery is no exception. In recent years, it has emerged as a powerful tool in the search for new drugs. By combining advanced algorithms, machine learning, and extensive data analysis, AI can accelerate the drug discovery process, reduce costs, and improve the success rate of new drug development [8].

One of the critical challenges in drug discovery is identifying potential drug candidates from vast libraries of chemical compounds. This process has traditionally been time-consuming and costly, often taking years and requiring significant financial resources; however, AI can analyze large datasets of chemical structures and predict their properties, enabling researchers to identify promising drug candidates quickly. By leveraging ma-

chine learning algorithms [8], AI can learn from existing data and make accurate predictions about the efficacy and safety of new compounds. This speeds up the drug discovery process and reduces the number of failed experiments, saving time and money [6, 7].

AI can also significantly contribute to drug discovery by identifying new drug targets. AI algorithms can analyze vast amounts of biological data, such as genomic and proteomic data, to identify potential targets for drug intervention [7]. By understanding the underlying molecular mechanisms of diseases, AI can help researchers identify novel targets that were previously unknown or overlooked. This opens up new avenues for drug development and allows researchers to explore innovative therapeutic approaches [9].

In addition to target identification, AI can aid in optimizing drug candidates. Once potential drug compounds have been identified, AI algorithms can predict their pharmacokinetic properties, such as absorption, distribution, metabolism, and excretion [9]. This information is crucial in determining whether a drug candidate is suitable for further development. By predicting absorption, distribution, metabolism, and excretion properties early in the drug discovery process, researchers can prioritize compounds with a higher likelihood of success and reduce the number of costly and time-consuming experiments [6].

Furthermore, AI can play a role in the design of clinical trials. AI algorithms can analyze patient and historical trial data to help optimize trial design and selection criteria. This can lead to more efficient and effective clinical trials, ultimately accelerating the development of new drugs. Additionally, AI can assist in analyzing trial data, enabling researchers to uncover hidden patterns and correlations that may have been missed using traditional statistical methods [10]. This can provide valuable insights into drug efficacy and safety, helping researchers make more informed decisions about drug development [5].

While AI holds great promise in drug discovery, it is essential to acknowledge its limitations. AI algorithms are only as good as the data they are trained on, and biases or errors in the training data can lead to inaccurate predictions [4]. Additionally, the complexity of biological systems poses a challenge for AI algorithms, as they often need help to capture the full complexity of molecular interactions. Therefore, researchers must validate and interpret the results generated by AI algorithms carefully [11].

Clinical trials

In recent years, the healthcare industry has been undergoing a revolution due to AI. Clinical trials are one of the areas where AI can have a significant impact. These trials are vital for testing the safety and effectiveness of new drugs and treatments. However, conducting clinical trials can be inefficient, expensive, and time-consuming. Below are some ways in which AI can help in clinical trials.

Patient recruitment

One of the most significant challenges in clinical trials is patient recruitment. Identifying suitable patients who meet specific criteria for a problem can be difficult. AI-powered tools can help identify potential patients by analyzing electronic health records, social media, and other data sources. This can significantly reduce the time and cost involved in patient recruitment [12].

Protocol design

AI can also help in designing clinical trial protocols. AI algorithms can identify the most effective study designs and endpoints by analyzing data from previous trials. This can help researchers develop more efficient and effective practices that produce better results [13].

Predictive analytics

AI algorithms can analyze data from clinical trials to identify patterns and predict outcomes. This can help researchers decide which treatments to pursue and which to abandon. Predictive analytics can also help identify potential safety issues before they become significant problems [14].

Drug development

AI can play a significant role in drug development. By analyzing large amounts of data, AI algorithms can identify potential drug targets and predict their efficacy. This can help researchers develop new drugs faster and more efficiently [12, 13, 15].

Real-time monitoring

Real-time monitoring during clinical trials using AI-powered tools can help researchers identify potential safety issues early on and take appropriate action. It can also help researchers adjust treatment protocols based on patient responses [15].

Data analysis

AI algorithms can analyze vast amounts of data from clinical trials to identify patterns and trends. This can help researchers gain new insights into disease mechanisms and treatment efficacy. Data analysis can also help identify subgroups of patients who may respond better to specific treatments [16].

Regulatory compliance

AI-powered tools can ensure regulatory compliance during clinical trials by automating data collection and reporting tasks. This can reduce the risk of errors and ensure that practices meet regulatory requirements [13].

The potential of AI is immense in revolutionizing clinical trials, making them more efficient, cost-effective, and accurate. AI can help researchers design better tests, recruit patients more effectively, and develop new treatments faster. As AI technology advances, we can expect to see even more significant progress in clinical trial research in the future [6, 8].

Staying compliant with evolving regulations and guidelines is crucial for organizations in today's rapidly changing regulatory landscape. AI can help ensure ongoing compliance by keeping up with these changes. Meanwhile, AI can process and analyze large amounts of data, making it an efficient tool to monitor regulatory updates continuously. By doing so, AI systems can identify changes in regulations and guidelines that may impact an organization's compliance requirements. This allows organizations to stay ahead of the curve and make necessary adjustments to their processes and procedures, thereby ensuring regulatory compliance [17].

AI offers an efficient way to automate compliance tasks. By utilizing machine learning algorithms, AI systems can learn from past compliance issues and detect patterns that may indicate non-compliance. This proactive approach enables organizations to address potential compliance risks early on.

In addition, AI-powered chatbots can provide real-time guidance and support to employees regarding compliance requirements. These chatbots can answer questions, offer relevant information, and provide training materials to ensure employees are well-informed and compliant.

AI technology can be instrumental in conducting audits and assessments. By analyzing large volumes of data, AI systems can identify anomalies, discrepancies, or potential compliance violations. This saves time and enhances the accuracy and effectiveness of audits. AI can revolutionize compliance management by keeping up with evolving regulations and guidelines. Its ability to process vast amounts of data, automate compliance tasks, provide real-time guidance, and conduct audits makes it an invaluable tool for organizations looking to maintain ongoing compliance in an ever-changing regulatory environment [18, 19].

Supply chain management

AI can potentially revolutionize supply chain management in the pharmaceutical industry. By leveraging AI technologies, pharmaceutical companies can improve efficiency, reduce costs, and ensure the availability of critical drugs. With its ability to analyze vast amounts of data and make real-time predictions, AI can help optimize various aspects of the supply chain, from inventory management to demand forecasting [20].

One area where AI can have a significant impact is inventory management. Traditionally, pharmaceutical companies have struggled with maintaining an optimal balance between overstocking and stockouts. More overstocking is needed to tie up capital and lead to wastage, while stockouts can result in lost sales and customer dissatisfaction. AI-powered inventory management systems can analyze historical data, current demand patterns, and other relevant factors to predict future demand accurately. This enables companies to optimize their inventory levels and reduce the risk of stockouts or overstocking [21].

Inventory management based on AI has the potential to revolutionize supply chain management; however, some challenges and limitations come with it. One of the primary challenges is the requirement for real-time data. AI algorithms need constant and accurate data to make informed decisions and optimize inventory levels. Without real-time data, AI-based inventory management may fail to respond quickly to changes in demand or supply, leading to stockouts or overstocking [22].

Another potential challenge is the risk of disruptions. AI-based inventory management relies heavily on technology and automation, which can be vulnerable to disorders like power outages or cyber-attacks. These disruptions can cause delays and inaccuracies in data collection and processing, leading to suboptimal inventory decisions [23].

Furthermore, there may be limitations in the ability of AI algorithms to account for complex human factors, such as consumer behavior and market trends. While AI can analyze vast amounts of data, it may struggle to interpret the nuances of human decision-making [24].

AI can also enhance supply chain visibility by providing real-time insights into the movement of drugs and other pharmaceutical products. By integrating AI with the Internet of Things devices, companies can track shipments in real time, monitor temperature and humidity conditions, and identify potential bottlenecks or delays. This level of visibility allows for proactive decision-making, such as rerouting shipments or adjusting production schedules to meet the demand [11, 25].

Another area where AI can make a significant impact is in demand forecasting. Accurate demand forecasting is crucial for pharmaceutical companies to ensure drug availability when and where needed [26]. AI algorithms can analyze various data sources, such as sales data, social media trends, weather patterns, and demographic information, to generate accurate demand forecasts. This enables companies to plan their production and distribution activities more effectively, reducing the risk of stockouts or excess inventory [27].

Furthermore, AI can help streamline the regulatory compliance process in the pharmaceutical industry. Compliance with various regulations and standards is essential to ensure product quality and patient safety; however, navigating the complex regulatory landscape can be time-consuming and resource-intensive. AI-powered systems can automate compliance checks by analyzing relevant regulations, guidelines, and product specifications. This saves time and reduces the risk of human error [26, 27].

In addition to improving efficiency and reducing costs, AI can enhance patient safety in the pharmaceutical supply chain. Counterfeit drugs pose a significant threat to public health, and it is estimated that they account for a substantial portion of global drug sales. AI technologies, such as blockchain, can help authenticate pharmaceutical products by creating a tamper-proof record of their journey through the supply chain. By ensuring the authenticity of drugs, AI can help protect patients from counterfeit or substandard medications [6, 28].

While the potential benefits of AI in supply chain management are clear, some challenges need to be addressed. One of the critical challenges is data quality. AI algorithms rely on accurate and reliable data to generate meaningful insights; however, data in the pharmaceutical industry can be fragmented, incomplete, or inconsistent. Companies need to invest in data management systems and processes to ensure the quality and integrity of their data [28].

Another challenge is the integration of AI technologies with existing systems and processes. Many pharmaceutical companies have legacy systems not designed to work with AI. Integrating AI technologies into these systems requires careful planning and coordination to ensure a smooth transition [29].

Furthermore, ethical considerations need to be considered when using AI in the pharmaceutical supply chain. For example, AI algorithms for demand forecasting or pricing decisions may raise concerns about fairness and equity. Companies must be transparent about how AI technologies are used and ensure they do not discriminate against specific patient populations or healthcare providers [25].

The pharmaceutical industry can benefit significantly from AI technology regarding supply chain management. By utilizing AI, companies can optimize inventory levels, improve supply chain visibility, accurately forecast demand, ensure regulatory compliance, and enhance patient safety; however, successfully implementing AI requires addressing challenges, such as data quality, ethical considerations, and system integration [4]. With careful planning and investment, AI can help pharmaceutical companies achieve operational excellence and efficiently deliver critical drugs to patients. Despite the potential benefits of AI, challenges must be addressed, such as ensuring the accuracy and reliability of AI algorithms. It is crucial to use quality data for training algorithms to achieve this, as biased data can lead to inaccurate predictions or decisions [30].

Ethics and responsibility

Ensuring ethical and responsible use of AI is crucial in the healthcare industry. As shown in Table 1, there are some ethical and legal concerns about AI use in the pharmaceutical industry. There are concerns that AI could lead to biased decisions, negatively impacting specific patient populations. Although AI has made significant strides in diagnosing diseases and predicting patient outcomes, there are still concerns about its ethical use [31, 32].

Table 1. Ethical and legal challenges of artificial intelligence in pharmaceutical

	Legal and Ethical Considerations of Artificial Intelligence in the Pharmaceutical Industry
1	Bias
2	Judgment
3	Transparency and explainability
4	Data protection
5	Displacement of workers
6	Data privacy and security
7	Liability and accountability

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One of the biggest challenges is to ensure that AI is used in a fair and unbiased way. AI algorithms could be biased against specific patient populations, leading to inaccurate diagnoses and treatments. To address this, healthcare providers must train their AI algorithms on diverse datasets representing various patient populations. Regular testing of algorithms for bias and taking corrective measures is also necessary [32, 33].

Another challenge is to ensure that AI is transparent and explainable. Patients have the right to understand how AI algorithms are being used to make decisions about their care. Therefore, healthcare providers must be transparent about the data they use to train their algorithms and the factors considered in the decision-making process [33].

Lastly, AI should be used to enhance patient care, not to replace human judgment. Healthcare providers must use AI ethically and responsibly while being mindful of potential risks, such as data breaches or privacy violations. By doing so, they can ensure that AI is used solely to improve patient outcomes. The healthcare industry needs to take steps to ensure that their AI algorithms are unbiased, transparent, and used to enhance patient care. This will help us harness the power of AI to improve health outcomes for all patients [34].

AI has emerged as a powerful tool in the pharmaceutical industry, transforming how drugs are discovered, developed, and prescribed. AI algorithms can analyze vast amounts of data, identify patterns, and make predictions with remarkable accuracy. However, using AI in pharmaceuticals raises essential legal and ethical considerations. Next, we will explore the role of laws in ensuring the responsible and ethical use of AI in the pharmaceutical industry [32, 34].

Regulatory landscape

The use of AI in pharmaceuticals is a topic that is still in development. Presently, there are no specific laws or regulations in place that govern the use of AI in this field. However, current rules and restrictions may apply to certain aspects of AI use in pharmaceuticals. For instance, data protection laws may regulate patient data collection, use, and sharing for AI analysis. Intellectual property laws may also safeguard AI algorithms and models that pharmaceutical companies develop. Additionally, the drug approval process may need to be modified to accommodate AI-driven drug discovery and development [15, 34, 35].

Regarding ethical considerations, the use of AI in the pharmaceutical industry raises several concerns. Transparency and explainability are among the most significant issues. AI algorithms can be complex and difficult to understand, making comprehending how they arrive at their conclusions challenging. This lack of transparency can raise questions about the fairness and accountability of decisions made by AI algorithms. To address this issue, pharmaceutical companies may be required by law to provide justifications or explanations for decisions made by AI algorithms [36].

Another ethical consideration is the potential impact of AI on jobs. The widespread use of AI in the pharmaceutical industry could result in the automation of specific tasks. This may lead to the displacement of workers and the need for retraining to adapt to changing job requirements. Companies that use AI in their operations must be mindful of these potential effects and take steps to mitigate them [37, 38].

Ethical considerations

The use of AI in the pharmaceutical industry brings up several ethical considerations. Transparency and explainability are among the significant concerns. AI algorithms can be intricate and opaque, making comprehending how they arrive at their conclusions challenging. This lack of transparency can raise questions about the fairness and accountability of decisions made by AI algorithms. To address this issue, laws may require pharmaceutical companies to provide justifications or explanations for decisions made by AI algorithms [38, 39].

Another ethical consideration is the potential for bias in AI algorithms. If the data used to train AI algorithms is biased or incomplete, the algorithms may perpetuate or amplify existing biases in healthcare. For instance, if a drug discovery algorithm is trained on a dataset that mainly includes data from a specific demographic group, it may be less effective or harmful for other groups. Laws may require pharmaceutical companies to ensure that their AI algorithms are trained on diverse and representative datasets to reduce bias [39].

Safety and efficacy

Ensuring the safety and efficacy of pharmaceuticals powered by artificial intelligence is a crucial concern. AI algorithms have the potential to generate new drug candidates and predict patient responses to existing drugs. However, these predictions must undergo rigorous testing and clinical trials to validate their accuracy. In addition, pharmaceutical companies may be required by law to demonstrate the safety and efficacy of AI-driven treatments before they are approved for use [40, 41].

Data privacy and security

Collecting, storing, and analyzing large amounts of patient data with the help of AI is a common practice in the pharmaceutical industry. However, protecting patient privacy and data security is of utmost importance. The General Data Protection Regulation in Europe has set guidelines for safeguarding personal data, which every pharmaceutical company must comply with. These companies must implement robust data protection measures to prevent unauthorized access or use of patient data [41].

Liability and accountability

The use of AI algorithms in pharmaceuticals can present challenges when trying to determine liability and accountability. If an AI algorithm makes a decision that ultimately harms a patient, who should be held responsible? Should it be the pharmaceutical company that created the algorithm, the healthcare provider that relied on the algorithm's recommendation, or the algorithm itself? To address these concerns, laws may need to clarify the legal framework for assigning liability and ensuring accountability in such cases [4].

The use of AI has the potential to significantly improve drug discovery, development, and patient care in the pharmaceutical industry; however, it is essential to address the legal and ethical challenges it presents. Laws provide a framework for AI's responsible and ethical use in this industry. By ensuring transparency, mitigating bias, ensuring safety and efficacy, protecting data privacy and security, and establishing liability and accountability, laws can help harness the full potential of AI while safeguarding the interests of patients and society as a whole [42].

Conclusion

The pharmaceutical industry stands to benefit significantly from the potential of AI. AI can improve drug discovery, clinical trials, personalized medicine, drug repurposing, manufacturing, and supply chain management. Researchers and pharmaceutical companies can make informed decisions, reduce costs, and improve patient outcomes by analyzing vast amounts of data using AI algorithms. However, it is crucial to address challenges such as data quality, ethics, and collaboration to harness AI's benefits fully in the pharmaceutical industry. Continued research and development will undoubtedly enable AI to play a significant role in shaping the future of healthcare.

Ethical Considerations

Compliance with ethical guidelines

This article is a review with no human or animal sample.

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Authors' contributions

Conceptualization and Supervision: Fatemeh Shaki; Searching article, data collection and writing-original draft: Milad Chahrdori and Danial Jahani; Writing the

legal section: Mohamadsadegh Amirkhanloo; Writing-review & editing: All authors.

Conflict of interest

The authors declared no conflict of interest.

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References

[1] DiMasi JA, Grabowski HG, Hansen RW. Innovation in the pharmaceutical industry: New estimates of R&D costs. J Health Econ. 2016; 47:20-33. [DOI:10.1016/j.jhealeco.2016.01.012] [PMID]

[2] Wong CH, Siah KW, Lo AW. Estimation of clinical trial success rates and related parameters. Biostatistics. 2019; 20(2):273-86. [DOI:10.1093/biostatistics/kxy072] [PMID] [PMCID]

[3] Russell SJ, Norvig P, Davis E. Artificial intelligence: A modern approach. London: Prentice Hall; 2009. [Link]

[4] Dill KA, MacCallum JL. The protein-folding problem, 50 years on. Science. 2012; 338(6110):1042-6. [DOI:10.1126/science.1219021] [PMID]

[5] Opderbeck DW. Artificial Intelligence in pharmaceuticals, biologics, and medical devices: Present and future regulatory models. Fordham Law Rev. 2019; 88(2):553. [Link]

[6] Vora LK, Gholap AD, Jetha K, Thakur RRS, Solanki HK, Chavda VP. Artificial intelligence in pharmaceutical technology and drug delivery design. Pharmaceutics. 2023; 15(7):1916. [DOI:10.3390/pharmaceutics15071916] [PMID] [PMCID]

[7] Sahu A, Mishra J, Kushwaha N. Artificial Intelligence (AI) in drugs and pharmaceuticals. Comb Chem High Throughput Screen. 2022; 25(11):1818-37. [DOI:10.2174/1386207325666211207153943] [PMID]

[8] 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. [DOI:10.1016/j.drudis.2020.10.010] [PMID] [PMCID]

[9] Lu M, Yin J, Zhu Q, Lin G, Mou M, Liu F, et al. Artificial intelligence in pharmaceutical sciences. Engineering. 2023; [Unpublished]. [DOI:10.1016/j.eng.2023.01.014]

[10] Tarle S, Kakad A, Shaikh M. Overview: Embracing tools of artificial intelligence in pharmaceuticals. Int J Sci Acad Res. 2023; 4(6):5749-55. [Link]

[11] Elbadawi M, McCoubrey LE, Gavins FKH, Ong JJ, Goyanes A, Gaisford S, et al. Harnessing artificial intelligence for the next generation of 3D printed medicines. Adv Drug Deliv Rev. 2021; 175:113805. [DOI:10.1016/j.addr.2021.05.015] [PMID]

[12] Schuhmacher A, Gatto A, Kuss M, Gassmann O, Hinder M. Big techs and startups in pharmaceutical R&D - A 2020 perspective on artificial intelligence. Drug Discov Today. 2021; 26(10):2226-31. [DOI:10.1016/j.drudis.2021.04.028] [PMID]

[13] Bhattamisra SK, Banerjee P, Gupta P, Mayuren J, Patra S, Candasamy M. Artificial intelligence in pharmaceutical and healthcare research. Big Data Cogn Comput. 2023; 7(1):10. [DOI:10.3390/bdcc7010010]

[14] Chen M, Decary M. Artificial intelligence in healthcare: An essential guide for health leaders. Healthc Manage Forum. 2020; 33(1):10-8. [DOI:10.1177/0840470419873123] [PMID]

[15] Bajwa J, Munir U, Nori A, Williams B. Artificial intelligence in healthcare: Transforming the practice of medicine. Future Healthc J. 2021; 8(2):e188-94. [DOI:10.7861/fhj.2021-0095] [PMID] [PMCID]

[16] Davenport T, Kalakota R. The potential for artificial intelligence in healthcare. Future Healthc J. 2019; 6(2):94-8. [DOI:10.7861/futurehosp.6-2-94] [PMID] [PMCID]

[17] Matthews J. Patterns and anti-patterns, principles, and pitfalls: Accountability and transparency in AI. AI Mag. 2020; 41(1):82-9. [DOI:10.1609/aimag.v41i1.5204]

[18] Mintz Y, Brodie R. Introduction to artificial intelligence in medicine. Minim Invasive Ther Allied Technol. 2019; 28(2):73-81. [DOI:10.1080/13645706.2019.1575882] [PMID]

[19] Nadikattu RR. The emerging role of artificial intelligence in modern society. Int J Creat Res Thoughts. 2016; [Unpublished]. [Link]

[20] Abbas K, Afaq M, Ahmed Khan T, Song WC. A blockchain and machine learning-based drug supply chain management and recommendation system for smart pharmaceutical industry. Electronics. 2020; 9(5):852. [DOI:10.3390/electronics9050852]

[21] Sharma R, Shishodia A, Gunasekaran A, Min H, Munim ZH. The role of artificial intelligence in supply chain management: Mapping the territory. Int J Prod Res. 2022; 60(24):7527-50. [DOI:10.1080/00207543.2022.2029611]

[22] Yogesh, Shrivastava S. Analysis of inventory level optimization using artificial intelligence approach. Smart Moves J Ijosthe. 2019; 6(2):1-7. [DOI:10.24113/ojssports.v7i2.90]

[23] Preil D, Krapp M. Artificial intelligence-based inventory management: A monte carlo tree search approach. Ann Oper Res. 2022; 1-25. [DOI:10.1007/s10479-021-03935-2]

[24] Ravinder H, Misra RB. ABC analysis for inventory management: Bridging the gap between research and classroom. Am J Bus Educ. 2014; 7(3):257–64. [DOI:10.19030/ajbe.v7i3.8635]

[25] Liotine M. Shaping the next generation pharmaceutical supply chain control tower with autonomous intelligence. J Auton Intell. 2019; 2(1):56-71. [DOI:10.32629/jai.v2i1.34]

[26] Nguyen A, Lamouri S, Pellerin R, Tamayo S, Lekens B. Data analytics in pharmaceutical supply chains: State of the art, opportunities, and challenges. Int J Prod Res. 2022; 60(22):6888-907. [DOI:10.1080/00207543.2021.1950937]

[27] Khatua A, Khatua A, Chi X, Cambria E. Artificial intelligence, social media and supply chain management: The

way forward. Electronics. 2021; 10(19):2348. [DOI:10.3390/electronics10192348]

[28] Merkuryeva G, Valberga A, Smirnov A. Demand forecasting in pharmaceutical supply chains: A case study. Procedia Comput Sci. 2019; 149:3-10. [DOI:10.1016/j.procs.2019.01.100]

[29] Mariappan MB, Devi K, Venkataraman Y, Lim MK, Theivendren P. Using AI and ML to predict shipment times of therapeutics, diagnostics and vaccines in e-pharmacy supply chains during COVID-19 pandemic. Int J Logist Manage. 2023; 34(2):390-416. [DOI:10.1108/IJLM-05-2021-0300]

[30] de Oliveira MB, Zucchi G, Lippi M, Cordeiro DF, da Silva NR, Iori M. Lead time forecasting with machine learning techniques for a pharmaceutical supply chain. Paper presented at: Proceedings of the 23rd International Conference on Enterprise Information Systems. 26 April 2021; Prague, Czech Republic. [DOI: 10.5220/0010434406340641]

[31] Safdar NM, Banja JD, Meltzer CC. Ethical considerations in artificial intelligence. Eur J Radiol. 2020; 122:108768. [DOI:10.1016/j.ejrad.2019.108768] [PMID]

[32] World Health Organization (WHO). Ethics and governance of artificial intelligence for health Internet]. 2021 [Updated 2024 February 24]. Available from: [Link]

[33] Gerke S, Minssen T, Cohen G. Ethical and legal challenges of artificial intelligence-driven healthcare. In: Bohr A, Memarzadeh K, editors. Artificial intelligence in healthcare. Amsterdam: Elsevier; 2020. [DOI:10.1016/B978-0-12-818438-7.00012-5]

[34] Schönberger D. Artificial intelligence in healthcare: A critical analysis of the legal and ethical implications. Int J Law Inf Technol. 2019; 27(2):171-203. [DOI:10.1093/ijlit/eaz004]

[35] Pesapane F, Volonté C, Codari M, Sardanelli F. Artificial intelligence as a medical device in radiology: Ethical and regulatory issues in Europe and the United States. Insights Imaging. 2018; 9(5):745-53. [DOI:10.1007/s13244-018-0645-y] [PMID] [PMCID]

[36] Stasevych M, Zvarych V. Innovative robotic technologies and artificial intelligence in pharmacy and medicine: Paving the way for the future of health care-a review. Big Data Cogn Comput. 2023; 7(3):147. [DOI:10.3390/bdcc7030147]

[37] Vollmer S, Mateen BA, Bohner G, Király FJ, Ghani R, Jonsson P, et al. Machine learning and artificial intelligence research for patient benefit: 20 critical questions on transparency, replicability, ethics, and effectiveness. BMJ. 2020; 368:l6927. [DOI:10.1136/bmj.l6927] [PMID]

[38] Ravali RS, Auguskani JPL, Reddy LKV, Narapureddy BR, Chellathurai A, Mavaluru D. Pioneering ethical boundaries: Empowering ai governance for the future of pharmaceutical and nursing sectors. Lat Am J Pharm. 2023; 42(3):695-701. [Link]

[39] Harrer S, Menard J, Rivers M, Green DV, Karpiak J, Jeliazkov JR, et al. Artificial intelligence drives the digital transformation of pharma. In: Krittanawong I, editor. Artificial intelligence in clinical practice. New York: Elsevier; 2024. [DOI:10.1016/B978-0-443-15688-5.00049-8]

[40] O'Sullivan S, Nevejans N, Allen C, Blyth A, Leonard S, Pagallo U, et al. Legal, regulatory, and ethical frameworks for development of standards in artificial intelligence (AI) and autonomous robotic surgery. Int J Med Robot. 2019; 15(1):e1968. [DOI:10.1002/rcs.1968] [PMID]

[41] Muehlematter UJ, Daniore P, Vokinger KN. Approval of artificial intelligence and machine learning-based medical devices in the USA and Europe (2015-20): A comparative analysis. Lancet Digit Health. 2021; 3(3):e195-203. [DOI:10.1016/S2589-7500(20)30292-2] [PMID]

[42] Schwendicke F, Samek W, Krois J. Artificial intelligence in dentistry: Chances and challenges. J Dent Res. 2020; 99(7):769-74. [DOI:10.1177/0022034520915714] [PMID]

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