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MEDICINE'S MIND: THE AI EVOLUTION IN HEALTHCARE

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ABSTRACT

The process of drug discovery is a complex, multi-faceted endeavor where various aspects of drug candidates, such as their effectiveness, pharmacokinetics, and safety profiles, must be enhanced to create the final, market-ready pharmaceutical product. The exploration or design of a novel drug candidate encompasses a multitude of parameters, rendering this undertaking a time-consuming, expensive, and occasionally fraught journey, with the potential for unfavorable outcomes. The exponential growth in computing power and the swift advancements in computational chemistry and biology have enabled the successful integration of computer-aided drug design techniques throughout the entire drug discovery and development pipeline. This integration has been instrumental in expediting the research process, mitigating the costs, and lowering the risks associated with preclinical and clinical trials. This paper delves into the profound impact of Artificial Intelligence (AI) on the pharmaceutical and medical domains, examining its capacity to bring about transformative changes. AI, endowed with the capacity to replicate human intelligence in learning, reasoning, and decision-making, has lead in a new era of innovation in healthcare and drug development.

KEYWORDS: AI, machine learning, NLP, pharmaceutical, healthcare.

WHAT IS ARTIFICIAL INTELLIGENCE?

Artificial intelligence, in essence, refers to the capability of a computer or robot to perform tasks that conventionally require human judgment and discernment.[1] In a broad context, Artificial Intelligence (AI) refers to the development of computer systems and algorithms that can perform tasks typically requiring human intelligence, such as learning, problem-solving, and decision-making. This extensive definition encompasses a diverse array of domains, including statistical and machine learning, clustering, pattern recognition, techniques based on similarity, logic, probability theory, and biologically inspired techniques such as evolutionary computing, fuzzy modeling, and neural networks, together referred to as "computational intelligence".[2,6] AI techniques find application in a variety of domains, including the curation of pertinent information, classification, data modeling, regression, prediction and optimization. Nonetheless, this review confines its attention to the precise facets of AI methodology that hold significance within the realm of the pharmaceutical industry and medical research.

INTRODUCTION

Artificial intelligence (AI) is rapidly permeating the healthcare sector, exerting a profound influence on disease diagnosis, process automation and clinical decision-making.[7] The expansive potential for AI within pharmaceutical and healthcare research stems from its capacity to scrutinize vast datasets across various modalities.[8] Current research explores the extensive functions of AI in healthcare and related domains, employing technologies such as robotic process automation, physical robots, natural language processing (NLP) and machine learning (ML).[9]

In the field of machine learning (ML), neural network models and deep learning techniques are harnessed to leverage a variety of attributes in scrutinizing imaging data for the early detection of medically significant factors, with a specific emphasis on diagnoses related to cancer.[10,11] Natural Language Processing (NLP) utilizes computational methods to grasp human language and extract its underlying semantics. There is a growing trend of amalgamating machine learning techniques with NLP to decipher unstructured information residing in databases and records, such as medical practitioners' observations and laboratory findings. The extraction of crucial insights from various textual and visual data sources plays a pivotal role in facilitating decision-making processes related to diagnosis and treatment alternatives.[12]

The continual advancements in this field open the path for patients to attain accurate and expedited diagnoses, along with personalized treatment approaches.[13]

AI-based solutions encompass platforms capable of harnessing various data types, including patient-reported symptoms, biometrics, imaging, biomarkers, and more. Advancements in AI empower the early detection of potential illnesses, thus increasing the probability of prevention through early diagnosis. Physical robots find utility in numerous healthcare domains, ranging from nursing, telemedicine, and radiology to surgical and rehabilitation applications.[14,15]

Robotic process automation leverages cost-effective technology that is easily programmable to perform structured digital tasks for administrative purposes. In the healthcare system, repetitive activities like updating patients' records, prior authorization, and billing can benefit from this technology.[16]

AI IN DRUG DISCOVERY AND DEVELOPMENT

The vast potential for generating a multitude of drug molecules within the chemical space encounters significant delays, primarily stemming from the lack of appropriate expertise. Nevertheless, the incorporation of AI in the process of developing drug has the potential to streamline and enhance this endeavor.[17,18]

The drug discovery process profoundly influences the entire pharmaceutical sector, encompassing various stages from the initial research phase involving finding targets and validating them, to the identification of potential molecules. A multitude of avenues are available to commence the search for small therapeutic compounds.[19] Ongoing research unveils new insights into diverse diseases and alternative routes for drug administration. These findings can pave the way for collaboration with pharmaceutical companies, facilitating large-scale trials and other significant initiatives geared towards the identification of specific molecular compounds.[20]

Target Identification: The early stage of the drug discovery journey commences with the identification and validation of the target, effectively setting the stage for the entire process. These targets for potential therapeutics primarily involve cellular or modular structures that occur naturally and play pivotal roles in pathogenic processes.[21] The ideal target molecule must not only be safe and effective but also align with the clinical requirements of patients, thereby paving the way for the eventual development of the preferred drug particle. After identifying the drug target, a systematic investigation into the means of action of the Active Pharmaceutical Ingredient (API) is conducted to ascertain its efficacy and qualify it as a potential therapeutic.

Hit Identification and Validation: Subsequently, the attention transitions towards evaluating whether the small molecule candidates demonstrate the desired impacts on the identified target entities. The identification of promising candidates, often referred to as "hits", is accomplished through a variety of methods, including high-throughput screening, knowledge-driven strategies, and virtual screening. It's crucial to underscore the significance of validating these hits, especially in the early stages of the screening process.[19]

Lead Validation: A key strategy in this phase is to concurrently work on multiple hit series in a randomized sequence, as the distinctive characteristics of certain successful series may lead to failure. By strategically concentrating on several structurally diverse hit series, it becomes possible to mitigate the risk associated with any one series, thereby enhancing the chances of success.[19]

Lead Optimization: In the pursuit of developing a preclinical drug candidate, a critical phase involves addressing the shortcomings of lead compounds while preserving their essential attributes. During this stage, the focus is on assessing whether the drug metabolizes correctly within the intended area of the body and identifying any potential concerns regarding side effects. It is strongly advisable to adopt an integrated approach, bringing together a team of experts spanning the realms of drug metabolism, medical chemistry, computational chemistry, and related fields. This collaborative effort empowers these specialists to offer invaluable insights and solutions, particularly in this advanced stage of the drug development process.[18,22]

Late Lead Optimization: This phase primarily involves the meticulous assessment of the pharmacological safety of a lead compound. Overlooking this crucial step could potentially jeopardize a drug's efficacy, safety, and pharmacokinetics in the later stages of development. Safety optimization endeavors to discover and advance leads with the most favorable safety profiles while eliminating the most toxic ones. By diligently evaluating risks at this juncture, it opens up more investment opportunities for lead compounds. Subsequently, if a drug successfully passes this rigorous scrutiny, it proceeds to preclinical and clinical trials.

Clinical Trials: Within the realm of drug discovery, clinical trials represent the most protracted phase, demanding substantial financial resources. Notably, even with substantial investments in terms of both time and capital directed towards clinical trials, the achievement rate for securing approvals from regulatory authorities such as the Food and Drug Administration (FDA) remains rather limited.[23,24,25] Clinical trials encounter a series of bottlenecks, any of which can lead to trial failures. These bottlenecks encompass challenges like inadequate participant enrollment, dropout rates during the trials, adverse effects associated with the test drug, and the occurrence of inconsistent or inconclusive data.

The oversight of multi-centered global trials entails significant expenses and consumes considerable time. Further complexities within the domain of clinical trials involve the timeframe extending from the "last subject's last visit" to the submission of data to regulatory bodies. This interval necessitates extensive data collection and analysis processes. However, the landscape of clinical trials is undergoing transformation with the aid of AI and digitization, offering solutions to mitigate these challenges.[26]

AI-powered predictive analytics can optimize clinical trial design, patient recruitment, and trial outcomes. Machine learning algorithms have the capability to process a wide range of data inputs, including patient characteristics, genetic information, and electronic medical records, with the aim of pinpointing patient groups that exhibit a higher likelihood of positive responses to specific treatments. Consequently, this facilitates the execution of more streamlined and precisely targeted clinical trials.[27]

Predicting Drug Efficacy and Toxicity: Within the field of medicinal chemistry, a notable utilization of AI centers on forecasting the efficacy and toxicity of prospective drug compounds. Conventional methods for drug discovery frequently rely on demanding, time-consuming experimental evaluations of how a compound affects the human body. This process is characterized by its sluggishness, high costs, and the inherent uncertainty and variability of results. AI techniques, notably Machine Learning (ML), are adept at surmounting these challenges. By sifting through extensive datasets, ML algorithms can discern hidden patterns and trends that might elude human researchers. This competence accelerates the discovery of new bioactive substances that come with minimal adverse effects, far surpassing the timeframes typically associated with traditional methodologies. One instance of this is the recent development of a Deep Learning (DL) algorithm, which involved the utilization of a dataset containing established drug compounds and their associated biological responses, which exhibited remarkable accuracy in predicting the activity of novel compounds.[28] Furthermore, substantial strides have been made in leveraging ML techniques, involving a thorough training process that utilizes vast databases containing both confirmed harmful and harmless compounds to mitigate the potential toxicity risks linked to prospective drug candidates.[29]

USE IN MEDICAL AND RESEARCH FIELD

Disease Diagnosis: Thorough disease analysis is of paramount importance when it comes to formulating compassionate treatment strategies and ensuring the well-being of patients. The inherent potential for human errors can impede precise diagnoses, while the potential for misinterpretation of the information generated compounds the complexity of this task. AI emerges as a valuable solution, offering diverse applications to instill confidence in accuracy and efficiency in the disease analysis process.[30] AI methods, ranging from machine learning to deep learning, play a pivotal role across a myriad of health-related domains, spanning the enhancement of novel clinical systems, management of patient information and records, and the treatment of a wide spectrum of diseases.[31,32] Notably, these AI techniques excel in accurately identifying and diagnosing various types of medical conditions. The integration of artificial intelligence (AI) as a means to advance healthcare presents unparalleled opportunities for improving patient and clinical outcomes, while concurrently reducing costs and enhancing efficiency. Moreover, AI's capabilities extend to pinpointing precise demographics or environmental regions where disease prevalence or high-risk behaviors are prevalent.[33]

Personalized Treatment: Precision medicine, also known as personalized medicine, represents a groundbreaking paradigm that customizes medical interventions to the unique attributes of each patient, encompassing factors such as their genetic composition, lifestyle preferences, and environmental exposures. In this transformative landscape, artificial intelligence (AI) assumes a pivotal role by delving into intricate datasets, unraveling intricate patterns, and deriving actionable intelligence, thus empowering the realization of precision medicine.[34]

The strides made in precision medicine are translating into tangible advantages, with early disease detection[35] and the formulation of individualized treatment plans becoming increasingly prevalent in the healthcare landscape.[36] These capabilities to personalize healthcare are made possible through the utilization of various data collection and analytical technologies. Significantly noteworthy is the fusion of high-throughput genotyping with the extensive embrace of Electronic Health Records (EHRs), offering researchers an exceptional opportunity to uncover fresh perspectives and characteristics from real-world clinical and biomarker information.[34]

Genomic Analysis: Genomic sequencing produces extensive genetic data, offering valuable insights into an individual's disease susceptibility, treatment responsiveness, and potential adverse reactions. AI algorithms come to the forefront in the analysis of this genomic data, pinpointing genetic variants linked to particular diseases or treatment outcomes. This empowers clinicians to make well-informed choices regarding personalized treatment strategies.[37,38]

Biomarker Discovery: The application of AI techniques facilitates the discovery of biomarkers, which are molecular indicators intricately linked to disease states, treatment responses, or prognoses. Through the analysis of comprehensive datasets encompassing genomics, proteomics, and clinical data, AI algorithms have the capacity to unveil intricate patterns and molecular signatures that hold the potential to serve as vital

biomarkers for distinct medical conditions. In a cascading effect, these discerned biomarkers assume a crucial function in the choice of accurately tailored treatment strategies and the continual evaluation of the efficacy of therapies.[39]

DRAWBACKS

Necessitates Human Supervision: AI, despite its capabilities, remains imperfect, demanding ongoing human oversight and vigilance. Consider robotic surgical technologies; they lack the capacity for empathy and strictly adhere to their programmed instructions. Even as AI presents data and recommendations, the ultimate decision still lies in the hands of human physicians. It is the healthcare professional who must exercise judgment, weighing the nuances of each patient's unique case and deciding whether to accept or reject the AI-derived guidance.[40]

Ethical Concerns: Since its inception, Artificial Intelligence has been accompanied by persistent ethical apprehensions. The foremost among these concerns is the question of accountability, surpassing even the prior issues of data privacy and security. Given the potential severity of the repercussions, the current framework demands that responsibility be assigned when unfavorable decisions are made, particularly within the realm of healthcare. AI is often regarded as an "black box" by many, as it raises concerns among researchers who fear the difficulty in discerning the intricate processes by which an algorithm arrives at a specific conclusion. The lack of universally acknowledged ethical principles governing the application of ML and AI in the healthcare sector has further complicated the situation. The ethical boundaries of deploying artificial intelligence (AI) in healthcare settings are a subject of debate, given the dearth of standardized principles to govern its ethical application.[41]

Social Concerns: The introduction of artificial intelligence (AI) into healthcare has stirred concerns about potential job displacement. Certain individuals express doubt and, in some cases, opposition to AI-driven endeavors, primarily stemming from concerns about potential job displacement. Nevertheless, this viewpoint predominantly stems from a misinterpretation of the multifaceted capabilities of AI.

Setting aside the time it will take for AI to reach a level where it can effectively replace healthcare professionals, the arrival of AI does not inherently equate to job obsolescence. Instead, it underscores the need for job roles to undergo transformation and adaptation. In this transition, we acknowledge the lasting human component and the intrinsic unpredictability found in various medical procedures, making them inherently less linear and structured than an algorithm-driven approach.[42]

Security Risks: AI-driven systems introduce significant concerns regarding data security and privacy, particularly in the realm of healthcare. Health records, being both crucial and highly vulnerable, often become prime targets for hackers during data breaches. Preserving the privacy and security of medical records stands as an utmost priority.[43]

The advancement of AI technology introduces a novel challenge, where users might inadvertently confuse artificial systems with human agents, potentially consenting to covert data collection, thereby raising profound privacy concerns.[44] In the context of data privacy, obtaining patient consent becomes a crucial factor, as healthcare providers could potentially grant wide-ranging access to patient data for AI research purposes without the need for individual patient consent. Recent legislative developments, such as the General Data Protection Regulation in Europe and the Health Research Regulations, both enacted in 2018, mark significant progress in mitigating these issues by imposing limitations on the gathering, application, and dissemination of personal data. Yet, the array of country-specific regulations can create challenges for cooperative research and worldwide data accessibility, potentially limiting the pool of data accessible for training AI systems on a global level.[42]

CONCLUSION

In conclusion, the incorporation of Artificial Intelligence (AI) into the pharmaceutical and medical industries signifies a transformative leap towards enhanced diagnosis, treatment, and drug development. AI-driven advancements in precision medicine, drug discovery, and patient care hold the potential to revolutionize healthcare, improve patient outcomes, and streamline various processes. However, the ethical and privacy considerations accompanying AI's prolific applications cannot be overlooked. As AI continues to evolve, striking a balance between reaping its benefits and addressing these concerns is imperative. It is clear that AI is not set to replace healthcare professionals but rather augment their capabilities. To harness the full potential of AI, it is vital to establish robust regulatory frameworks that ensure data security, patient privacy, and ethical use. The future of healthcare undoubtedly features AI as a crucial ally, but its ethical, legal, and regulatory dimensions must be thoughtfully navigated for a harmonious coexistence between technology and humanity.

REFERENCES

1. Mohd. Azhar, Paramjeet Kaur, Manveen Bhardwaj, Rajiv Sharma, Navpreet Kaur, Sandeep Kaur, Vanshika. Role Of Artificial Intelligence In Drug Design And Drug Discovery. Eur. Chem. Bull., 2023; 12(Special Issue 4): 5711-5725. www.eurchembull.com/uploads/paper/a87fb11a00196052fc57b9d48bde466f.pdf
2. Engelbrecht AP. Computational Intelligence: An Introduction. New York: J. Wiley, 2003. https://staff.fmi.uvt.ro/~daniela.zaharie/ma2017/boo

ks/Computational%20Intelligence%20An%20Introduction%20-%20Andries%20P.%20Engelbrecht.pdf
3. Konar A Computational Intelligence; Principles, Techniques And Applications. Berlin: Springer, 2005. https://doi.org/10.1007/b138935
4. Duda RO, Hart PE, Stork DG (2001). Pattern Classification. New York: J. Wiley, 2nd ed. https://www.researchgate.net/publication/228058014_Pattern_Classification
5. Webb A Statistical Pattern Recognition. New York: J. Wiley, 2002. http://www.ccas.ru/voron/download/books/machlearn/webb02statistical.pdf
6. Hastie T, Tibshirani R, Friedman J. The Elements Of Statistical Learning. Springer, 2001. https://www.sas.upenn.edu/~fdiebold/NoHesitations/BookAdvanced.pdf
7. Sunarti S, Rahman F F, Naufal M, Risky M, Febriyanto K, Masnina R. Artificial Intelligence In Healthcare: Opportunities And Risk For Future. Gac. Sanit., 2021; 35: S67–S70. DOI: 10.1016/j.gaceta.2020.12.019
8. Toepper M Dissociating Normal Aging from Alzheimer's Disease: A View from Cognitive Neuroscience. J. Alzheimer's Dis., 2017; 57: 331–352. doi: 10.3233/JAD-161099
9. Davenport T, Kalakota R The Potential For Artificial Intelligence In Healthcare. Futur. Healthc. J., 2019; 6: 94–98. doi: 10.7861/futurehosp.6-2-94
10. Fakoor R, Ladhak F, Nazi A, Huber M Using Deep Learning To Enhance Cancer Diagnosis And Classification. Conference: The 30th International Conference on Machine Learning (ICML 2013), WHEALTH workshop, 2013; 28: 3937–3949. https://www.cs.columbia.edu/~faisal/publications/whealth.pdf
11. Vial A, Stirling D, Field M, Ros M, Ritz C, Carolan M, Holloway L, Miller A A The Role Of Deep Learning And Radiomic Feature Extraction In Cancer-Specific Predictive Modelling: A Review. Transl. Cancer Res., 2018; 7: 803–816. doi: 10.21037/tcr.2018.05.02
12. Esteva A, Robicquet A, Ramsundar B, Kuleshov V, Depristo M, Chou K, Cui C, Corrado G, Thrun S, Dean J A Guide To Deep Learning In Healthcare. Nat Med., 2019; 25(1): 24–29. DOI:10.1038/s41591-018-0316-z
13. Horgan D, Romao M, Morré S A, Kalra D Artificial Intelligence: Power for Civilisation—And for Better Healthcare. Public Health Genom., 2019; 22(5-6): 145–161. doi: 10.1159/000504785
14. Hussain A, Malik A, Halim M U, Ali A M The Use Of Robotics In Surgery: A Review. Int. J. Clin. Pract., 2014; 68(11): 1376–1382. DOI:10.1111/ijcp.12492
15. Khan Z H, Siddique A, Lee C W. Robotics Utilization for Healthcare Digitization in Global COVID-19 Management. Int. J. Environ. Res. Public Health, 2020; 17(11): 3819. doi: 10.3390/ijerph17113819
16. Ribeiro J, Lima R, Eckhardt T, Paiva S Robotic Process Automation And Artificial Intelligence In Industry 4.0 - A Literature Review. Procedia Comput. Sci., 2021; 181(1): 51–58. DOI:10.1016/j.procs.2021.01.104
17. Mak K K, Pichika M R Artificial Intelligence In Drug Development: Present Status And Future Prospects. Drug Discov. Today, 2019; 24(3): 773–780. doi: 10.1016/j.drudis.2018.11.014
18. Vyas M, Thakur S, Riyaz B, BAnsal K Artificial Intelligence: The Beginning Of A New Era In Pharmacy Profession. Asian J. Pharm., 2018; 12(2): 72–76.
19. Nisha V Kalayil, Shona S D'souza, Showkhiya Y Khan, Pallavi Paul. Artificial Intelligence In Pharmacy Drug Design. Asian J Pharm Clin Res., 2022; 15(4): 21-27. DOI: http://dx.doi.org/10.22159/ajpcr.2022v15i4.43890
20. Paul D, Sanap G, Shenoy S, Kalyane D, Kalia K, Tekade R K Artificial Intelligence In Drug Discovery And Development. Drug Discov Today, 2021; 26(1): 80-93. doi: 10.1016/j.drudis.2020.10.010
21. Moingeon P, Kuenemann M, Guedj M Artificial Intelligence-Enhanced Drug Design And Development: Toward A Computational Precision Medicine. Drug Discov, 2021; 27(1): 215-22. doi: 10.1016/j.drudis.2021.09.006
22. Yang X, Wang Y, Byrne R, Schneider G, Yang S. Concepts Of Artificial Intelligence For Computer-Assisted Drug Discovery. Chem Rev., 2019; 119(18): 10520-94. doi: 10.1021/acs.chemrev.8b00728
23. Huss R The High Price Of Failed Clinical Trials: Time To Rethink The Model. Clinical Leader, 2016. Available online: https://www.clinicalleader.com/doc/the-high-price-of-failed-clinical-trials-time-to-rethink-the-model-0001
24. Wong C H, Siah K W, Lo A W Estimation of clinical trial success rates and related parameters. Biostatistics., 2019; 20: 273–286. doi.org/10.1093/biostatistics/kxx069
25. Thorlund K, Haggstrom J, Park J J, Mills E J Key Design Considerations For Adaptive Clinical Trials: A Primer For Clinicians. BMJ, 2018; 360: k698. https://doi.org/10.1136/bmj.k698
26. Kolluri S, Lin J, Liu R, Zhang Y, Zhang W Machine Learning and Artificial Intelligence in Pharmaceutical Research and Development: A Review. AAPS J., 2022; 24: 19. doi: 10.1208/s12248-021-00644-3.
27. 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; ISSN (online), 2019; 2347-2154. DOI: 10.21276/IJIPSR.2019.07.10.506
28. Hansen K, Biegler F, Ramakrishnan R, Pronobis W, Von Lilienfeld O A, Müller K R, Tkatchenko A.

Machine Learning Predictions Of Molecular Properties: Accurate Many-Body Potentials And Nonlocality In Chemical Space. J. Phys. Chem. Lett., 2015; 6(12): 2326–2331. https://doi.org/10.1021/acs.jpclett.5b00831
29. Santín E P, Solana R R, García M G, Suárez M D M G, Díaz G D B, Cabal M D C, Rojas J M M, Sánchez J I L Toxicity Prediction Based On Artificial Intelligence: A Multidisciplinary Overview. Wiley Interdiscip. Rev. Comput. Mol. Sci., 2021; 11: e1516. https://doi.org/10.1002/wcms.1516
30. Subrat Kumar Bhattamisra, Priyanka Banerjee, Pratibha Gupta, Jayashree Mayuren, Susmita Patra, Mayuren Candasamy. Artificial Intelligence in Pharmaceutical and Healthcare Research. Big Data and Cognitive Computing, 2023; 7(1): 10. DOI:10.3390/bdcc7010010
31. Uysal G, Ozturk M Hippocampal Atrophy Based Alzheimer's Disease Diagnosis Via Machine Learning Methods. J Neurosci Methods, 2020; 337: 1–9. doi: 10.1016/j.jneumeth.2020.108669
32. Zebene A, Årsand E, Walderhaug S, Albers D, Mamykina L, Botsis T, Hartvigsen G Data-Driven Modeling And Prediction Of Blood Glucose Dynamics: Machine Learning Applications In Type 1 Diabetes. Artif Intell Med., 2019; 98: 109–134. doi: 10.1016/j.artmed.2019.07.007
33. Yogesh Kumar, Apeksha Koul, Ruchi Singla, Muhammad Fazal Ijaz (2022). Artificial Intelligence In Disease Diagnosis: A Systematic Literature Review, Synthesizing Framework And Future Research Agenda. J Ambient Intell Humaniz Comput., 2023; 14(7): 8459–8486. doi: 10.1007/s12652-021-03612-z
34. Kevin B. Johnson, Wei-Qi Wei, Dilhan Weeraratne, Mark E Frisse, Karl Misulis, Kyu Rhee, Juan Zhao, Jane L Snowdon (2020). Precision Medicine, AI, And The Future Of Personalized Health Care. Clin Transl Sci., 2021 Jan; 14(1): 86–93. doi: 10.1111/cts.12884
35. Marc van der Schee, Hazel Pinheiro, Edoardo Gaude Breath Biopsy For Early Detection And Precision Medicine In Cancer. E cancer medical science, 2018; 12: ed84. doi: 10.3332/ecancer.2018.ed84
36. Ryan J Hartmaier, Lee A Albacker, Juliann Chmielecki, Mark Bailey et al. High-Throughput Genomic Profiling Of Adult Solid Tumors Reveals Novel Insights Into Cancer Pathogenesis. Cancer Res., 2017; 77: 2464–2475. DOI: 10.1158/0008-5472.CAN-16-2479
37. Sumit Das, Aritra Dey, Akasl Pal, Nabamita Roy Applications of Artificial Intelligence in Machine Learning: Review and Prospect. International Journal of Computer Applications, 2015; 115(9). DOI: 10.5120/20182-2402
38. Prasad Patil, Nripesh Kumar Nrip, Ashok Hajare, DigvijayHajare, Mahadev K. Patil, Rajesh Kanthe, Anil T. Gaikwad Artificial Intelligence and Tools in Pharmaceuticals: An Overview. Research Journal of Pharmacy and Technology, 2023. DOI: 10.52711/0974-360X.2023.00341
39. Nihar Ranjan Kar Advancement Of Artificial Intelligence in Pharmacy: A Review. Shodhsamhita, 2022; 9(2): 514-529. https://www.researchgate.net/publication/364358395_ADVANCEMENT_OF_ARTIFICIAL_INTELLIGENCE_IN_PHARMACY_A_REVIEW
40. What Are The Pros And Cons Of Implementing AI In Healthcare? 2022. Open Access News. https://www.openaccessgovernment.org/what-are-the-pros-and-cons-of-implementing-ai-in-healthcare/140058/
41. Bangul Khan, Hajira Fatima, Ayatullah Qureshi, Sanjay Kumar, Abdul Hanan, Jawad Hussain, Saad Abdullah (2023). Drawbacks Of Artificial Intelligence And Their Potential Solutions In The Healthcare Sector. Biomed Mater Devices., 2023 Feb 8; 1–8. doi: 10.1007/s44174-023-00063-2
42. FDA Permits Marketing Of Artificial Intelligence-Based Device To Detect Certain Diabetes-Related Eye Problems, 2018. FDA.
43. Baowaly M K, Lin C C, Liu C L, Chen K T Synthesizing Electronic Health Records Using Improved Generative Adversarial Networks. J. Am. Med. Inform. Assoc., 2019; 26(3): 228–241. doi: 10.1093/jamia/ocy142
44. S Ji, Q Gu, H Weng, Q Liu, P Zhou, Q He, R Beyah, T Wang De-Health: All Your Online Health Information Are Belong To Us. arXiv preprint, 2020. DOI 10.1109/ICDE48307.2020.00143