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Review Article

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Artificial Intelligence in Medical Diagnostics and Drug discovery: A Review

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ABSTRACT

Artificial intelligence (AI) is the field of computer sciences devoted to building smart machines capable of performing tasks that typically require human-level intelligence. The application of novel technologies like AI, machine learning (ML) and Deep learning (DL) in medical diagnostics could play a role in transforming the future of health care. Artificial neural networks such as deep neural networks or recurrent networks drive this area. AI helping patient care and intelligent health systems. AI can analyse identifying and diagnosing diseases more accurately and quickly. DL (a subset of ML) constitute the virtual component of AI plays a pivotal role in drug discovery. The widespread adoption of ML, in particular DL, in multiple scientific disciplines, and the advances in computing DL hardware and software, among other factors, continue to fuel this development-based approaches have only begun to address some fundamental problems in drug discovery. Research and development work is going worldwide. Here we tried to present AI application in various fields from health sector to drug discovery. We analysed the literature through PubMed and other ways of scientific search engines and also understand AI applications and presented in this paper. The finding are significant and understand how computational power is applied in the development of AI, its growing amount of digitized data, are analysed with accuracy and speed by AI. In this review, we discuss the basics of AI followed by an outline of its application in medical diagnostics and drug discovery.

Key Words: Artificial intelligence, Machine learning, Deep learning, Health care, Algorithms, Drug discovery

INTRODUCTION

Artificial intelligence (AI) is the field of computer sciences devoted to building smart machines capable of performing tasks that typically require human-level intelligence. The term AI was coined by John McCarthy.[1] AI, as an idea is old.[2] AI utilizes computer algorithms to carry out multiple tasks. ML is a subset of AI that allows computers to learn without explicit human programming by recognizing patterns, making predictions, and self-correcting after mistakes are made. DL (DL, a subset of ML) constitute the virtual component of AI. [3] DL depends on multiple layers in a neural network, a computer algorithm that allows accurate recognition of images, sounds, and language. DL, allows layered neural networks to learn an abstract representation of often very complex data sets. AI and ML are not new and already in the early years the potential, risks and limits of AI have been hotly debated.

DL takes this further, allowing the AI to adjust errors on its own, without direct human intervention, allowing for complex behaviour-like performances.

Modern medicine is faced with the challenge of acquiring, analysing, and applying the huge amount of knowledge necessary to solve complex clinical problems.[4]

AI applications in the medical field have two main branches: virtual and physical. [5] In medical diagnostics AI required other data sources such as ultrasound, magnetic resonance imaging, mammography, genomics, computed tomography scan, etc. AI is the most efficient in identifying the diagnosis of different types of diseases. [6] A similar feature was introduced with Artificial Neural Networks (ANNs) and ML, inspired by the networked neurons of the biological brain. The time for AI in biology has arrived. Human intellectual limits in collecting data, integrating data, and testing hypotheses spanning multiple subdisciplines are the primary reason biology became fragmented in the first place.

Predicting an organism's phenotype is extraordinarily difficult because it requires integrating processes and information across multiple scales of biological organization, from molecules to an organism's environment.[7] All around the world researchers and scientists used machine and DL mod-

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els to detect the diseases such as neuro degenerative disease like Alzheimer's and other diseases skin, liver, heart, etc. AI has the potential to revolutionize diagnostic approaches in haematology. [8] AI strives to simulate human behaviour and intelligence; ML refers to the automatic detection of patterns and associations within the data.[9]

Presently many health care workers struggling with the lack of well-organized mechanisms for integrating and reconciling these data ahead of their current silos. The cost of healthcare is increasing significantly due to the requirement for state-of-the-art infrastructure.[10]

AI APPLICATIONS IN MEDICAL DIAGNOSTICS

The evaluation is mainly depending on medical conditions or diseases by analysing medical history, test results and symptoms. Due to the recent advances in AI in medical diagnostics and it is improving prediction efficiency, accuracy, and speed. In the field of medicine, AI can improve the patient outcomes and is more effective and efficient healthcare system. Digital data is also a basic prerequisite for the application of emerging AI techniques. Like other AI algorithms, Quantum can be a best choice. [11]

AI in image processing

AI will analyse the data in (Fig-1) five stages1) image acquisition, (2) image pre-processing, (3) image segmentation, (4) feature extraction and selection, and (5) classification. Commonly used in disease diagnosis to detect cancer, diabetes, and tuberculosis.[12,13]

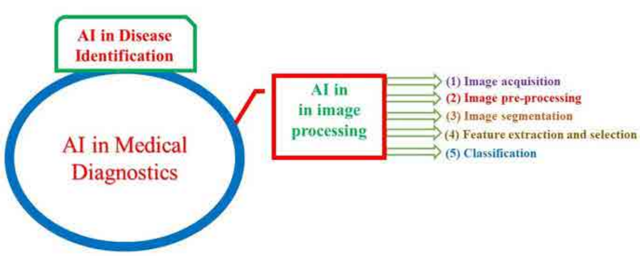

Figure 1

In medical imaging, pre-processing of the acquired image is conducted to enhance the visual quality of an image by reducing noises and identifying the image's texture, colour, and shape to produce a clean image. [14,15,16] AI offer exciting prospects for more efficient and effective use of medical images. [17]

AI used in DL, has been explored extensively in the diagnosis of COVID-19, especially in the field of lung detection images, including CT images, X-ray images and ultrasound images. ML models are useful in the prediction of SARS-CoV-2 infection risk of patients with severe diseases during COVID-19 pandemic.[18]

Both ML and DL methods have become valuable tools for the discovery of various diseases. AI is one of the diagnostic tools to screen and detect chronic diseases such as cancer, diabetes, and among patient.[19,20]

If anyone want to fully understand AI, they must know the use and applicability of diverse techniques such as Decision Tree, RNN, KNN, SVM, Naïve Bayes, Ada Boost, Random Forest, K-Mean Convolutional neural networks (CNN), Deep-CNN, clustering, Generative Adversarial Networks (GAN), and Long short-term memory (LSTM) and many others for various disease detection system. [21, 22]

Due to the remarkable improvement in technology in the biological field AI has important role and its current applications and advances like Cytomorphology. [23,24,26,27,27,28]

AI in disease identification

In tumour cytogenetics, chromosome anomalies, including numerical and structural abnormalities, are quite common and pose a further challenge for automated approaches.[29,30,31,32,33.] The Newly developed Deep Learning designs are useful to find variety of data.[34,35] The applications of ML in pathology are expanding rapidly, with recent advances in anatomic pathology, including breast mammography, and prostate pathology. [38,39] The goal of DL used for clinical management of people with cancer.[40] DL may also improve concordance for assessments typically subject to high interrater variability, such as histopathologic grading of prostate cancer using Gleason patterns.

Numerous studies have produced ML and DL-assisted cancer prediction models to detect cancer from previously accessible data with better accuracy, sensitivity, and specificity. Diagnosis of lung cancer covers imaging diagnosis; pathological and genetic diagnosis. Deep neural networks have also been developed to predict distant metastatic recurrence rate and disease-specific survival in early-stage melanoma.[41]

AI is having an astoundingly positive effect on the field of pathology, including breast pathology. [42] CRC represents the third most diagnosed malignancy in both men and women. [43] ML, a subfield of AI recognizes specific features or lesions.[44,45]

The effect of a deep learning-based CAD model on polyp and adenoma detection rates was previously studied.[46] Even though the colonoscopy is widely accepted as the "gold-standard" of CRC screening methods; it is worth mentioning that the current procedure is not 100% sensitive. Currently, a research group used ML techniques and specific phenotypic studies accompanied by mechanistic studies, chemical genetics, and omics assays to successfully predict disease-drug pairs with the intent of repurposing existing drugs for CRC treatment. Recent research focuses on human-computer collaboration, where gains in accuracy were measured even with imperfect CNNs.[47] Dermatopathologists may potentially identify patients with aggressive tumours that may benefit from further adjuvant treatments.[48] One study demonstrates the potential efficacy of AI-based instruction in improving diagnostic performance in dermatopathology and highlights the overall acceptance of this technology by learners.[49] CNN (DL of AI) used for diagnosis.[50]

AI allows a continuous and burden-free remote monitoring of the patient's symptoms and biomarkers. AI will introduce a paradigm shift in diabetes care from conventional management strategies to building targeted data-driven precision care.

AI and ML algorithms have proved to be of crucial importance in other imaging techniques like Cardiac MRI particularly for ventricular segmentation. AI can act as an essential tool that can help physicians improve their clinical judgment, and provide a precise diagnosis of diseases like HF. The logistic regression model of AI has been applied in the diagnosis of congestive heart failure (CHF). ML can segment the heart chambers from Cardiac MRIs and these segmentations yield imaging biomarkers to predict CHF.[51] In recent years, AI has been used in various aspects of LC diagnosis and treatment, especially in the field of imaging.[52]

DL algorithm performs view classification with the same accuracy as a board-certified echocardiographer.[53] The number of ML-based studies of cardiac Computed Tomography has multiplied over the last decade. ML algorithms helped select the most important cine-image-derived texture features to distinguish between patients with myocardial infarction and control subjects. Dyslipidemia is a prominent risk factor for cardiovascular diseases and one of the primary independent modifiable factors of diabetes and stroke.[54]

AI tools that have been extensively investigated for AD diagnosis.[55] Ultrasonography is a diagnostic tool providing a cross-sectional examination, its real-time evaluation capacity and absence of ionizing radiation are its outstanding strengths. The problems associated with imaging technique is the noise and artifacts. AI gains may be expected to increase diagnostic accuracy, provide reliable support to radiologists in clinical decisions, reduce the workload of radiologists, increase their efficiency.[56] Pre-clinical studies of Dental and maxillofacial radiology (DMFR), and AI based can identify exact locations. [57]. AI is useful personalized diagnosis and treatment of atrial fibrillation.

AI is extensively used for identification of Gastric Problems. [58,59] It has been applied to benign gastrointestinal lesions, tumors, early cancer, inflammatory bowel disease, gallbladder, pancreas, and other diseases. AI also played improvement in small bowel capsule endoscopy.[60]

AI will eventually help manage patients with liver disease, predict the clinical outcomes, and reduce medical errors. Detecting fatty liver disease and making risk stratification.[61] Predicting the primary origin of liver metastasis. Detecting metastatic liver malignancy and Kidney Disease,[62] Spine Care,[63] Intracoronary Imaging[64]. AI such as ML, may enable us to utilize neuroimaging for individual diagnosis of psychiatric disorder or treatment response prediction.[65]

In Imaging of the lung,[66] AI shown prominent clinical diagnosis and imaging are critical for minimizing the morbidity and mortality associated with ischemic strokes.

Diffuse lung diseases are a heterogeneous group of disorders that can be difficult to differentiate by imaging using traditional methods of evaluation. The overlap between various disorders results in difficulty when medical professionals attempt to interpret images. AI offers new tools for the evaluation and quantification of imaging of patients with diffuse lung disease.[67] AI algorithms are also useful in the identification of brain disorders.[68]

Globally, diabetic retinopathy (DR) is regarded as a major cause of vision loss. DL systems are effective and accurate in the detection of DR from digital fundus photographs or optical coherence tomography.[69] AI is expected to play an important role in this aspect in the coming decades. Diagnosis of primary and secondary bone tumours, breast, lung, and colon neoplasms.[70,71]

Digital technological solutions such as AI have emerged as a potential adjunct for myopia management[72] and diabetes prevention [73]. AI provides a powerful tool in glycosylation analysis[74].

Computer-aided systems can provide physicians with assistance in detecting and diagnosing precancerous lesions or early-stage CRC. Several novel algorithms have shown promising results for the accurate detection and characterization of suspected lesions.[75] AI also have other applications including Thoracic imaging.[76] Applications are increasingly important in arrhythmia monitoring, ranging from conventional algorithmic analysis for rhythm determination to more complex deep ML methods that have led to the realization of fully automated human like rhythm determination in real-time and PET Imaging.[77]

AI in drug discovery

Drug research and development (Fig-2) is a complex, expensive, time-consuming procedure and has a high attrition rate.[78]

Drug design poses many challenging problems in terms of selection of relevant information, data modelling, classification, prediction, and optimization. In addition to the development of AI, the computational power of hardware and the available data for modelling were also significantly improved to facilitate this progress. [79]

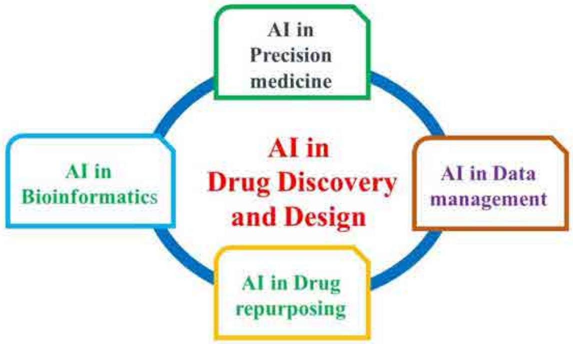

Figure 2

ML based approaches have very been useful in drug discovery. [80,81] One important aspect of the success of ML for property prediction is access to large datasets, which is a prerequisite for applying AI.[82]

AI integrates many branches of statistical and ML, pattern recognition, logics, and probability theory as well as biologically motivated approaches, such as neural networks. Drug designing and development is an important area of research for pharmaceutical companies. AI techniques are being used in drug design, to classify candidate compounds in terms of their activity and other properties. In the 1960s, AI used for QSAR based drug discovery. [83]

Low efficacy, off-target delivery, time consumption, and high cost impose a hurdle and challenges that impact drug design and discovery. Novel data mining, curation, and management techniques provided critical support to recently developed modelling algorithms. [84] AI methods are being used to find correlations between patterns of genetic variations and expression profiles with clinical and other phenotypes and to identify predictive fingerprints of disease states, progression, and results of therapeutic interventions.

The adoption and use of DL methods for molecular docking has been extremely successful mainly due to the accessibility to DL computational frameworks such as Tensor flow. Drug discovery is a high-risk, length and expensive process.[85]

Recently developed DL and relevant modelling studies can be implemented for safety and efficacy evaluations of drug molecules based on big data modelling and analysis. ANN had their first heyday in molecular informatics and drug discovery approximately two decades ago. Compared with some of the other life sciences, their application in drug discovery is still limited. Many areas of the chemical sciences have already benefited from the ever-advancing developments in DL.[86]

Major increase in the use of ML-based quantitative structure–activity relationship (QSAR) models for generating target-specific compounds.[87] Owing to the development of ML theory and the accumulation of pharmacological data, AI technology, as a powerful data mining tool, has cut a figure in various fields of the drug design, such as virtual screening, activity scoring, quantitative structure-activity relationship (QSAR) analysis, *denovo* drug design, and *in silico* evaluation of absorption, distribution, metabolism, excretion and toxicity (ADME/T) properties.[88] Drug discovery has experienced a relatively late resurgence in the interest for DL.[89]

AI in precision medicine

ML has been used in precision medicine to predict patient success on various treatment protocols given specific characteristics of the treatment and the patient's disease.

Algorithms, such as Nearest-Neighbour classifiers, RF, extreme learning machines, SVMs, and deep neural networks (DNNs), are used for VS based on synthesis feasibility and can also predict in vivo activity and toxicity. [90,91] Researchers compared multiple classical ML models and their ability to classify patients with Crohn's disease using genome-wide genotyping data. [92] In the field of medicine medical imaging, the hype of recent years about AI has had a significant impact.

The rise of AI in medicine is often associated with "superhuman" abilities and precision medicine.[93] Scientists have demonstrated the applicability of AI in delivering novel synthetically feasible bioactive compounds for the first time.[94]

The main hindrance in drug repositioning is diagnosing and identifying the unique drug-disease relationship.[95] AI used in oncology studies [96] and natural product study.[97]

The application of AI cannot be limited to selection of the most optimal compound and predict its' *in vivo* activity. AI-based drug repurposing is in the developmental stage, several examples have shown encouraging results.[98] AI technologies, such as visible neural networks, 70 incorporate the AI model's inner workings into real systems of biomedical sciences (e.g.; human and animal). AI's potential ability to identify new candidate therapies that can be made available for clinical trials rapidly and, if approved, merged into health care is unparalleled, making AI a centrepiece of advanced technologies. AI approaches, coupled with big data, have the potential to substantially improve the efficiency and effectiveness of drug repurposing and aid medical decision making of therapeutic benefits with real-world evidence for various complex human diseases, such as COVID-19 and AD.

The term big data describes a collection of data sets that are so large and complex that they are too difficult to process with traditional data analysis tools.

AI in data management

The need for novel computational techniques, including data mining/generation, curation, storage, and management, brings new challenges and opportunities to the research community. Identification of actionable disease subtypes is increasingly powered by AI using integrative methods combining diverse data modalities.[99] AI has been successfully used to develop individualized drug compounds themselves, with personalized cancer vaccines being one of the prime examples.[100]

AI in bioinformatics

The massive growth of bioinformatics resources creates new opportunities to apply computational approaches for drug repurposing in AD. AI network medicine approach to AD rests on the underlying hypothesis that cellular networks gradually adjust to chronic processes of disease initiation and progression, leading to progressive shifts in local and global network properties and system states that underlie an evolving pathogenesis of AD.[101]

Precision medicine has raised high hopes to improve the success rate of Phase II and III clinical trials by tailoring treatment options to the characteristics of patient subgroups based on differences in molecular profiles, lifestyle, and environmental factors.

AI has been used in *denovo* drug design, activity scoring, virtual screening and *In silico* evaluation in the properties (absorption, distribution, metabolism, excretion, and toxicity) of a drug molecule. Various pharmaceutical companies have teamed up with AI companies for faster progress in the field of drug development, along with the healthcare system. [102]

AI in drug repurposing

Drug repurposing also called drug repositioning, reprofiling, redirecting, and drug rediscovery is a strategy for identifying new therapeutic purposes for approved drugs in medical indications beyond the scope of their original therapeutic use. In recent years, several computational approaches have been developed for a more systematic drug repurposing process.[103] AI for drug repurposing is the use of real-world data, such as electronic health records, in searching for effective repurposed drug candidates.[104]

Computer-aided drug design can reduce these costs by early discontinuation of failed compounds and reducing the number of experiments needed. The advent of machine learning-based prediction tools and optimisation algorithms that could handle complex, non-numerical solution representations (e.g., chemical graphs) enabled the application of multi-objective optimisation (MOO) in molecular design.

Structure-based drug discovery (SBDD) are based on the abilities of the drug to bind to multiple protein-binding sites. ML algorithms have relevant and potential applications at almost all steps of the SBDR pipeline and beyond, such as drug screening, target screening, target structure/binding site prediction, lead optimization, prediction of drug–drug interactions, and ADMET property prediction.

DISCUSSION

AI can analyse identifying and diagnosing diseases more accurately and quickly. AI is versatile use in drug discovery, disease identification, drug repurposing bioinformatics and data management. In the past few years, drug repurposing research has benefited greatly by the systematic adoption of computational strategies spanning a large area of unique methodologies and approaches.

CONCLUSION

Modern medicine is faced with the challenge of acquiring, analysing, and applying the huge amount of knowledge necessary to solve complex clinical problems.AI model can only perform as good as the data that is used to train it. Another clear limitation for the application of AI in healthcare is the "accuracy-interpretability" trade-off. Furthermore, there are still missing areas, novel ideas, which cannot be learned from data, giving a combination of human and machine intelligence a good perspective. AI approaches, coupled with big data, have the potential to substantially improve the efficiency and effectiveness of drug repurposing. ML has been used in precision medicine to predict patient success on various treatment protocols given specific characteristics of the treatment and the patient's disease. The implementation of these new technologies is steadily growing and is providing a brilliant chance to healthcare specialists to be prepared for the new era of Diagnostics and Drug discovery.

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REFERENCES

1. Schmidt-Erfurth U, Sadeghipour A, Gerendas BS, Waldstein SM, Bogunović H. Artificial intelligence in retina. Prog Retin Eye Res. 2018; 67:1-29.

2. Hassoun S, Jefferson F, Shi X, Stucky B, Wang J, Rosa E. Artificial Intelligence for Biology. Integr Comp Biol. 2022 ;61(6):2267-2275.
3. Hamet P, Tremblay J. Artificial intelligence in medicine. Metabolism. 2017:69S: S36-S40
4. Ramesh AN, Kambhampati C, Monson JR, Drew PJ. Artificial intelligence in medicine. Ann R Coll Surg Engl. 2004; 86(5):334-8.
5. Amisha, Malik P, Pathania M, Rathaur V.K. Overview of artificial intelligence in medicine. J Family Med Prim Care. 2019;8(7):2328-2331.
6. Kumar Y, Koul A, Singla R, Ijaz M.F. 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
7. Burnett KG, Durica DS, Mykles DL, Stillman JH, Schmidt C. Recommendations for Advancing Genome to Phenome Research in Non-Model Organisms. Integr Comp Biol. 2020 ;60(2):397-401.
8. Shouval R, Fein JA, Savani B, Mohty M, Nagler A. Machine learning and artificial intelligence in haematology. Br J Haematol. 2021;192(2):239-250.
9. Walter W, Pohlkamp C, Meggendorfer M, Nadarajah N, Kern W, Haferlach C, et al. Artificial intelligence in hematological diagnostics: Game changer or gadget? Blood Rev. 2023;58:101019
10. Alami H, Lehoux P, Auclair Y, de Guise M, Gagnon MP, Shaw J, et al. Artificial Intelligence and Health Technology Assessment: Anticipating a New Level of Complexity. J Med Internet Res. 2020; 22(7):e17707.
11. Al-Antari MA. Artificial Intelligence for Medical Diagnostics-Existing and Future AI Technology! Diagnostics (Basel). 2023;13(4):688.
12. Shin Y, Yang J, Lee YH, Kim S. Artificial intelligence in musculoskeletal ultrasound imaging. Ultrasonography. 2021;40(1):30-44
13. Kabongo JM, Nel S, Pitcher RD. Analysis of licensed South African diagnostic imaging equipment. Pan Afr Med J. 2015;22:57
14. Wasekar UW, Bathla R.K. Machine learning for diabetic retinopathy detection using image processing Int. J. Recent Technol. Eng: 2021; 9 (5):209-21516
15. Prabhu N, Bhoir D, Shanbhag N. Diabetic retinopathy screening using machine learning for hierarchical classification Int. J. Innov. Technol. Explor. Eng. 2019;8 (10): 1943-1948
16. Shravani HK. Lung cancer detection using local energy-based shape histogram (LESH) feature extraction using adaboost machine learning techniques. Int. J. Innov. Technol. Explor. Eng. 2020;9 (3) :167-171.
17. Li M, Ding Z, Gore JC. Identification of White Matter Networks Engaged in Object (Face) Recognition Showing Differential Responses to Modulated Stimulus Strength. Cereb Cortex Commun. 2020;1(1):tgaa067.
18. Laatifi M, Douzi S, Bouklouz A, Ezzine H , Jaafari J, Zaid Y, et al. Machine learning approaches in Covid-19 severity risk prediction in Morocco. J Big Data. 2022;9(1):5.
19. Abedi V, Khan A, Chaudhary D, Misra D, Avula V, Mathrawala D, et al. Using artificial intelligence for improving stroke diagnosis in emergency departments: a practical framework. Ther Adv Neurol Disord. 2020;13:1756286420938962.
20. Wahl B, Cossy-Gantner A, Germann S, Schwalbe N.R. Artificial intelligence (AI) and global health: how can AI contribute to health in resource-poor settings? BMJ Glob Health. 2018;3(4):e000798.
21. Owasis M, Arsalan M, Choi J, Mahmood T, Park K. Artificial intelligence-based classification of multiple gastrointestinal diseases using endoscopy videos for clinical diagnosis. J Clin Med. 2019;8:786.
22. Nithya A, Ahilan A, Venkatadri N, Ramji D, Palagan A. Kidney disease detection and segmentation using artificial neural network and multi kernel k-means clustering for ultrasound images. Measurement. 2020;149:106952
23. Alomari YM, Sheikh Abdullah SN, Zaharatul Azma R, Omar K. Automatic detection and quantification of WBCs and RBCs using iterative structured circle detection algorithm. Comput Math Methods Med. 2014; 979302.
24. Alférez S, Merino A, Bigorra L, Rodellar J. Characterization and automatic screening of reactive and abnormal neoplastic B lymphoid cells from peripheral blood. Int J Lab Hematol. 2016;38(2):209-19
25. Alférez S, Merino A, Mujica LE, Ruiz M, Bigorra L, Rodellar J. Automatic classification of atypical lymphoid B cells using digital blood image processing. Int J Lab Hematol. 2014;36(4):472-80.
26. Kimura K, Tabe Y, Ai T Takehara I, Fukuda H, Takahashi H, et al. A novel automated image analysis system using deep convolutional neural networks can assist to differentiate MDS and A.A. Sci Rep. 2019;9(1):13385.
27. Wu YY, Huang T.C, Ye RH, Fang WH, Lai SW, Chang P.Y, et al. A Hematologist-Level Deep Learning Algorithm (BMSNet) for Assessing the Morphologies of Single Nuclear Balls in Bone Marrow Smears: Algorithm Development. JMIR Med Inform. 2020;8(4):e15963.
28. El Achi H, Khoury J.D. Artificial Intelligence and Digital Microscopy Applications in Diagnostic Hematopathology. Cancers (Basel). 2020;12(4):797.
29. Delshadpour S. Reduced size multi-layer perceptron neural network for human chromosome classification. In: Proceedings of the 25th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (IEEE Cat. No.03CH37439). IEEE. 2004; 3.2249–52.
30. Haferlach C, Hänselmann S, Walter W, Volkert S, Zenger M, Kern W, Haferlach T. Artificial intelligence substantially supports chromosome banding analysis maintaining its strengths in hematologic diagnostics even in the era of newer technologies. Blood. 2020;136:47–8.
31. Oskouei BC, Shanbehzadeh J. Chromosome classification based on wavelet neural network. In: 2010 International Conference on Digital Image Computing: Techniques and Applications. IEEE. 2010; 605–10.
32. Qiu Y, Lu X, Yan S, Tan M, Cheng S, Li S, et al. Applying deep learning technology to automatically identify metaphase chromosomes using scanning microscopic images: an initial investigation. In: Chen WR (ed). Biophotonics and Immune Responses XI. SPIE. 2016; 9709:
33. Sharma M, Saha O, Sriraman A, Hebbalaguppe R, Vig L, Karande S. Crowdsourcing for chromosome segmentation and deep classification. In: 2017 IEEE Conference on Computer Vision and Pattern Recognition Workshops (CVPRW). IEEE. 2017; 786–93.
34. Wainberg M, Merico D, Delong A, Frey BJ. Deep learning in biomedicine. Nat Biotechnol. 2018;36(9):829-838.
35. Zou J, Huss M, Abid A, Mohammadi P, Torkamani A, Telenti A. A primer on deep learning in genomics. Nat Genet. 2019; 51(1):12–8.
36. LeCun Y, Bengio Y, Hinton G. Deep learning. Nature. 2015; 521(7553): 436–444.
37. Dias R, Torkamani A. Artificial intelligence in clinical and genomic diagnostics. Genome Med. 2019;11(1):70.

38. Yoon J.H, Kim EK. Deep Learning-Based Artificial Intelligence for Mammography. Korean J Radiol. 2021: 22(8);1225-1239.
39. Sari CT, Gunduz-Demir C. Unsupervised feature extraction via deep learning for histopathological classification of colon tissue images. IEEE Trans Med Imaging. 2019;38(5):1139-1149.
40. Walsh S, de Jong EEC, van Timmeren JE, Ibrahim A, Compter I, Peerlings J, et al. Decision support systems in oncology. JCO Clin Cancer Inform. 2019;3(3):1–9.
41. Hekler A, Utikal J.S, Enk AH, Solass W, Schmitt M, Klode J, et al. Pathologist-level classification of histopathological melanoma images with deep neural networks. Eur J Cancer. 2019; 115:79-83.
42. Yousif M, van Diest PJ, Laurinavicius A, Rimm D, van der Laak J, Madabhushi A, Schnitt S, Pantanowitz L. Artificial intelligence applied to breast pathology. Virchows Arch. 2022;480(1):191-209.
43. Bray F, Ferlay J, Soerjomataram I, Siegel RL, Torre LA, Jemal A. Global cancer statistics 2018: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin. 2018:68(6):394-424. Epub 2018 Sep 12. Erratum in: CA Cancer J Clin. 2020;70(4):313.
44. Ting DSW, Peng L, Varadarajan AV, Keane PA, Burlina PM, Chiang MF, et al. Deep learning in ophthalmology: the technical and clinical considerations. Prog Retin Eye Res. 2019; 72: 100759.
45. Campbell CG, Ting DSW, Keane PA, Foster PJ. The potential application of artificial intelligence for diagnosis and management of glaucoma in adults. Br Med Bull. 2020;134(1):21-33.
46. Wang P, Berzin TM, Brown JRG, Bharadwaj S, Becq A, Xiao, X et al.. Real-time automatic detection system increases colonoscopic polyp and adenoma detection rates: A prospective randomised controlled study. Gut 2019; 68: 1813–1819.
47. Tschandl P. Artificial intelligence for melanoma diagnosis. Ital J Dermatol Venerol. 2021;156(3): 289-299.
48. Kulkarni PM, Robinson EJ, Pradhan JS, Gartrell-Corrado R.D, Rohr BR, Trager M.H, et al. Deep learning based on standard H&E images of primary melanoma tumors identifies patients at risk for visceral recurrence and death. Clin Cancer Res. 2020;26(5):1126-1134.
49. Crowley R.S, Legowski E, Medvedeva O, Tseytlin E, Roh E, Jukic D. Evaluation of an intelligent tutoring system in pathology: effects of external representation on performance gains, metacognition, and acceptance. J Am Med Inform Assoc. 2007;14(2):182-190.
50. Wells A, Patel S, Lee JB, Motaparthi K. Artificial intelligence in dermatopathology: Diagnosis, education, and research. J Cutan Pathol. 2021;48(8):1061-1068
51. Farah Y, Syed Muhammad IS, Aisha N, Syed Muhammad S, Adina J, Sana K, et al. Artificial intelligence in the diagnosis and detection of heart failure: the past, present, and future. Rev. Cardiovasc. Med. 2021; 22(4), 1095–1113.
52. Chen HY, Ge P, Liu JY, Qu JL, Bao F, Xu CM, et al. Artificial intelligence: Emerging player in the diagnosis and treatment of digestive disease. World J Gastroenterol. 2022; 28:28(20):2152-2162.
53. Feigenbaum H. Evolution of echocardiography. Circulation. 1996;93(7):1321-7.
54. Liu J, Dan W, Liu X, Zhong X, Chen C, He Q, Wang J. Development and validation of predictive model based on deep learning method for classification of dyslipidemia in Chinese medicine. Health Inf Sci Syst. 2023;11(1):21.
55. Verma RK, Pandey M, Chawla P, Choudhury H, Mayuren J, Bhattamisra SK, et al. An Insight into the Role of Artificial Intelligence in the Early Diagnosis of Alzheimer's Disease. CNS Neurol Disord Drug Targets. 2022; 21(10):901-912.
56. Dicle O. Artificial intelligence in diagnostic ultrasonography. Diagn Interv Radiol. 2023;29(1):40-45.
57. Hung K, Montalvao C, Tanaka R, Kawai T, Bornstein MM. The use and performance of artificial intelligence applications in dental and maxillofacial radiology: A systematic review. Dentomaxillofac Radiol. 2020;49(1):20190107.
58. Liscia DS, D'Andrea M, Biletta E, Bellis D, Demo K, Ferrero F, et al. Use of digital pathology and artificial intelligence for the diagnosis of Helicobacter pylori in gastric biopsies. Pathologica. 2022;114(4):295-303.
59. Hsiao Y.J, Wen Y.C, Lai W.Y, Lin Y.Y, Yang Y.P, Chien Y, et al. Application of artificial intelligence-driven endoscopic screening and diagnosis of gastric cancer. World J Gastroenterol. 2021;27(22).2979-2993.
60. Trasolini R, Byrne MF. Artificial intelligence and deep learning for small bowel capsule endoscopy. Dig Endosc. 2021;33(2):290-297.
61. Biswas M, Kuppili V, Edla DR, Suri HS, Saba L, Marinhoe R.T, et al. Symtosis: A liver ultrasound tissue characterization and risk stratification in optimized deep learning paradigm. Comput Methods Programs Biomed. 2018;155:165–177.
62. Yuan Q, Zhang H, Deng T, Tang S, Yuan X, Tang W, et al. Role of Artificial Intelligence in Kidney Disease. Int J Med Sci. 2020; 17(7):970-984.
63. Gutman MJ, Schroeder GD, Murphy H, Flanders AE, Vaccaro AR. Artificial Intelligence in Spine Care. Clin Spine Surg. 2021;34(4):121-124.
64. Fedewa R, Puri R, Fleischman E, Lee J, Prabhu D, David et al. Artificial Intelligence in Intracoronary Imaging. Curr Cardiol Rep. 2020; 22(7):46.
65. Takamiya A, Tazawa Y, Kudo K, Kishimoto T. [Artificial Intelligence in Psychiatry]. Brain Nerve. 2019;71(1):15-23.
66. San José Estépar R. Artificial intelligence in functional imaging of the lung. Br J Radiol. 2022;95(1132):20210527.
67. Chan J, Auffermann WF. Artificial Intelligence in the Imaging of Diffuse Lung Disease. Radiol Clin North Am. 2022;60(6):1033-1040.
68. Minoshima S, Cross D. Application of artificial intelligence in brain molecular imaging. Ann Nucl Med. 2022;36(2):103-110.
69. Huang X, Wang H, She C, Feng J, Liu X, Hu X, et al. Artificial intelligence promotes the diagnosis and screening of diabetic retinopathy. Front Endocrinol (Lausanne). 2022; 29:13:946915.
70. O'Connell AM, Bartolotta TV, Orlando A, Jung SH, Baek J, Parker KJ. Diagnostic Performance of an Artificial Intelligence System in Breast Ultrasound. J Ultrasound Med. 2022;41(1):97-105.
71. Vogrin M, Trojner T, Kelc R. Artificial intelligence in musculoskeletal oncological radiology. Radiol Oncol. 2020;55(1):1-6.
72. Foo LL, Ng W.Y, Lim G.YS, Tan TE, Ang M, Ting DSW. Artificial intelligence in myopia: current and future trends. Curr Opin Ophthalmol. 2021;32(5):413-424.
73. Ou Q, Jin W, Lin L, Lin D, Chen K, Quan H. LASSO-based machine learning algorithm to predict the incidence of diabetes in different stages. Aging Male. 2023;26(1):2205510.
74. Li H, Chiang A.W.T, Lewis N.E. Artificial intelligence in the analysis of glycosylation data. Biotechnol Adv. 2022;60:108008.
75. Mitsala A, Tsalikidis C, Pitiakoudis M, Simopoulos C, Tsaroucha AK. Artificial Intelligence in Colorectal Cancer Screening, Diagnosis and Treatment. A New Era. Curr Oncol. 2021;28(3):1581-1607.
76. Chassagnon G, Vakalopoulou M, Paragios N, Revel MP. Artificial intelligence applications for thoracic imaging. Eur J Radiol. 2020;123:108774.

77. Bradshaw TJ, McMillan AB. Anatomy and Physiology of Artificial Intelligence in PET Imaging. PET Clin. 2021;16(4):471-482.
78. Waring MJ, Arrowsmith J, Leach A.R, Leeson P.D, Mandrell S, Owen R.M, et al. An analysis of the attrition of drug candidates from four major pharmaceutical companies. Nat. Rev. Drug Discov. 2015;14:475–86.
79. Zhu H. Big Data and Artificial Intelligence Modelling for Drug Discovery. Annu Rev Pharmacol Toxicol. 2020;60:573-589.
80. Kayala MA, Azencott CA, Chen JH, Baldi P. Learning to predict chemical reactions. J Chem Inf Model. 2011;51(9):2209-22.
81. Sadowski P, Fooshee D, Subrahmanya N, Baldi P. Synergies Between Quantum Mechanics and Machine Learning in Reaction Prediction. J Chem Inf Model. 2016;56(11):2125-2128.
82. Hessler G, Baringhaus KH. Artificial Intelligence in Drug Design. Molecules. 2018;23(10):2520.
83. Hansch C, Fujita T. ρ-σ-π Analysis. A method for the correlation of biological activity and chemical structure. J. Am. Chem. Soc. 1964; 86:1616–26.
84. 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):1315-1360.
85. DiMasi JA, Faden LB. Competitiveness in follow-on drug R&D: a race or imitation? Nat Rev Drug Discov. 2011; 10(1):23-7.
86. Gawehn E, Hiss J.A, Schneider G. Deep Learning in Drug Discovery. Mol Inform. 2016;35(1):3-14.
87. Luukkonen S, van den Maagdenberg HW, Emmerich MTM, van Westen GJP. Artificial intelligence in multi-objective drug design. Curr Opin Struct Biol. 2023;79:102537.
88. Zhong F, Xing J, Li X, Liu X, Fu Z, Xiong Z, et al. Artificial intelligence in drug design. Sci China Life Sci. 2018; 61(10):1191-1204.
89. Schneider G. Mind and machine in drug design. Nat. Mach. Intell. 2019;1(3):128–130.
90. Álvarez-Machancoses Ó, Fernández-Martínez JL. Using artificial intelligence methods to speed up drug discovery. Expert Opin Drug Discov. 2019;14(8):769-777.
91. Dana D, Gadhiya SV, St Surin LG, Li D, Naaz F, Ali Q, et al. Deep Learning in Drug Discovery and Medicine: Scratching the Surface. Molecules. 2018;23(9):2384.
92. MacEachern SJ, Forkert N D. Machine learning for precision medicine. Genome. 2021;64(4):416-425.
93. Nensa F, Demircioglu A, Rischpler C. Artificial Intelligence in Nuclear Medicine. J Nucl Med. 2019: 60(Suppl 2):29S-37S.
94. Merk D, Friedrich L, Grisoni F, Schneider G. De Novo Design of Bioactive Small Molecules by Artificial Intelligence. Mol Inform. 2018;37(1-2):1700153.
95. Mohanty S, Harun Ai Rashid M, Mridul M, Mohanty C, Swayamsiddha S. Application of Artificial Intelligence in COVID-19 drug repurposing. Diabetes Metab Syndr. 2020;14(5):1027-1031.
96. Wieder R, Adam N. Drug repositioning for cancer in the era of AI big omics and real-world data. Crit Rev Oncol Hematol. 2022;175:103730.
97. Arora S, Chettri S, Percha V, Kumar D, Latwal M. Artificial intelligence: a virtual chemist for natural product drug discovery. J Biomol Struct Dyn. 2023;26:1-10.
98. Richardson P, Griffin I, Tucker C, Smith D, Oechsle O, Phelan A, et al. Baricitinib as potential treatment for 2019-nCoV acute respiratory disease. Lancet. 2020;395(10223):e30-e31.
99. Boniolo F, Dorigatti E, Ohnmacht AJ, Saur D, Schubert B, Menden MP. Artificial intelligence in early drug discovery enabling precision medicine. Expert Opin Drug Discov. 2021;16(9):991-1007.
100. Ott PA, Hu-Lieskovan S, Chmielowski B, Govindan R, Naing A, Bhardwaj N, et al. A Phase Ib Trial of Personalized Neoantigen Therapy Plus Anti-PD-1 in Patients with Advanced Melanoma, Non-small Cell Lung Cancer, or Bladder Cancer. Cell. 2020;183(2):347-362.e24.
101. Fang J, Pieper AA, Nussinov R, Lee G, Bekris L, Leverenz JB, et al. Harnessing endophenotypes and network medicine for Alzheimer's drug repurposing. Med Res Rev. 2020;40(6):2386-2426.
102. Sahu A, Mishra J, Kushwaha N. Artificial Intelligence (AI) in Drugs and Pharmaceuticals. Comb Chem High Throughput Screen. 2022; 25(11):1818-1837.
103. Tanoli Z, Vähä-Koskela M, Aittokallio T. Artificial intelligence, machine learning, and drug repurposing in cancer. Expert Opin Drug Discov. 2021;16(9):977-989.
104. Zhou Y, Wang F, Tang J, Nussinov R, Cheng F. Artificial intelligence in COVID-19 drug repurposing. Lancet Digit Health. 2020; 2(12):e667-e676.