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Review Article

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Review on Artificial Intelligence in Pharmacological Imaging Analysis: Transforming Drug Discovery and Patient Care

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Abstract

Artificial intelligence is highly evolving in the field of healthcare particularly in Medical Imaging. It provides tremendous opportunities in the areas of advanced identification of the illness. Artificial intelligence enables accurate and quicker diagnosis along with an individualised and customizable patient care. These developments have immensely been beneficial to medical professionals to a great extent. This review takes a comprehensive look at the Artificial intelligence in medical imaging analysis and the technologies used for the same. It also focuses on the wide spectrum of usage of Artificial intelligence in medical imaging such as disease detection, image categorisation, workflow optimization and automation. In spite of having such huge advantages of early disease detection, it experiences hurdles of data privacy and moral concerns etc. However, the future of Artificial intelligence looks promising and optimistic with developments targeting the revolution in the healthcare and patient care arena.

Keywords: Artificial Intelligence, Medical Imaging, Healthcare, Revolution, Patient Care

Introduction

Artificial Intelligence (AI) is the synthesis of theories, algorithms, and computational frameworks that enables a range of tasks that traditionally require human intelligence, including speech recognition, language understanding, visual perception, reasoning, and decision-making. It's a single word that covers a wide range of techniques, including rule-based reasoning, computer vision, deep learning, machine learning, and natural language processing. Artificial Intelligence has the potential to greatly accelerate data analysis by identifying patterns in the data and producing more informed and timely decisions [1].

Healthcare and AI

Artificial intelligence is rapidly transforming healthcare, offering a multitude of benefits. AI algorithms can analyse vast medical datasets, enabling earlier disease detection, improved diagnosis accuracy, and even personalised treatment plans. Imagine AI spotting subtle anomalies in medical scans or predicting potential health risks based on a patient's unique data. This technology empowers healthcare professionals to intervene sooner and deliver more effective care, ultimately leading to better patient outcomes and a healthier future.

AI or artificial intelligence is widely used in medical science these days [2-4]. It is used for diagnosing illness, drug discovery and development, improving communication between physicians and patients transcribing prescriptions. AI not only diagnoses the problem but also treats patients. It has proven to be more efficient than humans and recently computer algorithms, state-of the art, have achieved accuracies which are beyond human expertise [5]. It is only a matter of time before it replaces certain roles within the medical sciences. Artificial intelligence can provide help in various patient care and health intelligent systems. AI with the help of machine learning as well as deep learning helps in health care [5,6]. Data resources from the past records help in better diagnosis of diseases. It is also used in ultrasound, magnetic resonance imaging, genomics etc. It is used in treating diseases like Alzheimer, stories, hypertension, cerebrovascular, etc [7].

Genomics, an interdisciplinary field within molecular biology, explores genomes' composition, evolution, mapping, and editing. It encompasses an organism's entire DNA, including genes and their three-dimensional structure [8]. However, applying AI in functional genomics faces various challenges, such as understanding biological processes, managing data, and addressing ethical concerns like data fairness and bias. Despite these challenges, AI can enhance bioinformatics by improving experimental design and model validation, predicting protein functions, and identifying regulatory variations, particularly in cancer genomics. Next Generation Sequencing (NGS) generates vast amounts of genomic data, necessitating AI-driven preprocessing methods like Google AI's Deep Variant, which employs deep learning to enhance variant calling accuracy [9].

The use of AI in drug discovery is multifaceted. Advanced computational method can efficiently analyse biological network data, uncovering hidden patterns and relationships. These techniques enable researchers to categorise, group, and predict future behaviours within these networks, leading to a deeper understanding of biological processes. Target identification and validation are the first steps in the drug discovery pipeline [10]. Drug repurposing strategies, powered by advanced computational methods, offer a rapid approach to identify existing medications that could combat new and emerging diseases. This technology is capable of bringing in new ideas and concepts in the areas of drug discovery, identification and administration of treatment, and results the patient would get in different types of illnesses [11]. As such it would become a very essential and useful means in evidence-based medicine [12]. AI can be used to bring in synergies in the design of clinical trials including selecting the patients (also called as substance), adjusting and administering the dosage of medicines given to them and tracing back any possible safety hazards leading out of it. This will certainly result in more accurate and data driven trials thereby contributing significantly in the field of drug discovery.

AI in oncology has numerous uses that enhance various aspects of cancer care [13-15]. It aids in early detection through the analysis of medical images, for the identification of tumours at their initial stages [16]. AI helps in making precise medicine possible by customising therapies and treatments to each patient, hence, maximising efficacy while minimising negative effects, using genetic data and patient records. Moreover, AI assists in radiation therapy planning, clinical decision-making, prognosis prediction, and remote patient monitoring, thereby contributing to improved diagnosis, treatment, and management of cancer, thereby enhancing patient outcomes [16].

AI in Medical Imaging

The branch of medical imaging informatics utilises various factors such as knowledge, statistics and communication technologies. ICT i.e. Information and Communication Technologies in general to deliver proper healthcare facilities through medical images. Over the past 30 years, this field has seen a continuous stream of advancements in various medical imaging modalities, encompassing a wide range - from complex human physiology and disease processes to routine clinical applications [17]. As stated by the SIIM (Society for Imaging Informatics in Medicine), the primary aim of informatics in medical imaging is enhancing the efficacy, precision, and dependability of healthcare delivery through medical imaging [18].

Artificial intelligence (AI) is poised to revolutionise healthcare, particularly in the realm of medical image diagnosis. The future, with its immense assurance for the development of AI-powered preventative healthcare, personalised medicine, and improved disease management through the combination of radiomics with various types of data, such as genomics, proteomics, and demographics is very bright. Local healthcare providers are actively adopting AI technologies to streamline labour-intensive and repetitive tasks, such as medical image analysis [19].

Types of AI Technologies Used in Medical Imaging

The application of artificial intelligence in the healthcare sector is constantly evolving. Its need and importance increase with new innovations. Many areas of patient care along with administrative procedures could be revolutionised by these innovations and technologies. This includes the 3 Ps i.e. Payer, Provider, and pharmaceutical organisations [20].

Machine learning (ML)

The term machine learning (ML) refers to a group of techniques that automatically discovers the trends in the given dataset and makes use of those trends in order to foresee future possible data combinations or facilitate making decisions in unpredictable situations [21].

Machine learning is a statistical system that fits the models as per the dataset and enables these models to "grasp" through data-operating model training. ML is an established type of artificial intelligence. In 2018, Deloitte conducted a poll taking into account a total of 1,100 US managers who had their companies already pursuing artificial intelligence. Here, 63% of the organisations reported put machine learning into use [22].

A list of around 343 AI/ML enabled medical devices that the US FDA had given approval for as of June 2021 was released in September 2021 by the Digital Health Center of Excellence [23]. The FDA website defined artificial intelligence as "a device or product that can imitate intelligent behaviour or mimic human learning and reasoning" [24] however the precise standards for compiling the list were not made clear. Medical specialist panels for radiology (around 70.3%) and cardiology (around 12.0%) reviewed and evaluated the majority of the devices. Since the mid-2010s, the number of these gadgets has increased dramatically. The 510(k) premarket notification procedure cleared the majority of devices (95.0%), with software accounting for 69.4% of those cleared as medical devices (SAMDS). The most often used applications for the 241 radiology-related gadgets were image reconstruction (14.1%) and diagnostic aid (48.5%). Taking into account the 117 radiology-associated devices for assistance in diagnostics, 20.5% of them were evolved for breast lesion assessment and 14.5% were put in place for cardiac function assessment on the echocardiogram. Taking into account the 41 cardiology-related devices, the most frequent applications were found to be electrocardiography-based arrhythmia detection (around 46.3%) and hemodynamics & monitoring of vital signs (around 26.8%) [25].

Neural Networks

There are different forms of ML, since the 1960s, neural networks have been widely used in healthcare research. It is a more complex form of ML. They have been implemented for classifying applications such as forecasting diseases. It finds solutions by considering inputs, outputs, and variables that link inputs and outputs. Neural network models that have multiple layers of variables that predict outcomes are the most complex types of ML [20]. The application of deep learning is used in radiomics for detection of significant characteristics in imaging data is growing in popularity. The two types of machine learning techniques used to train algorithms are supervised and unsupervised (Figure. 3). Supervised learning uses inference from training data to construct a function that replicates output. To prepare training data for this method, nominal or numerical vectors representing the attributes of the input data and matching output data are created. Regression is the broad term used to describe the training process when the output data has a continuous value. On the other hand, the procedure is called classification if the resultant data has a classified value. Unsupervised learning, in contrast to supervised learning, infers a function to characterise hidden structures from unlabelled input data rather than taking output data into account. Since the examples are not labelled, the accuracy cannot be objectively assessed. Unsupervised learning is similar to a cluster analysis in statistics and focuses on the ways that dimensionality reduction and clustering make up the vector space representing the hidden structure, even though it encompasses many other solutions involving summarising and explaining key features of the data.

Adapted from

- Gaussian Mixture Model as GMM
- Locally-Linear Embedding as LLE
- Principal Component Analysis as PCA
- Stochastic Gradient Descent as SGD
- Support Vector Classification as SVC
- Support Vector Regression as SVR
- Variational Bayesian Gaussian Mixture Model as VBGMM

A standard algorithm for classification is a simple Bayesian model that focuses on the distribution of probability of the input data. The approach is not difficult at all and thus it achieves its best in certain domains. The assignment of rRNA sequences is one such example. Given its advantages of regularisation and convex optimization, SVM, the most used classification method usually shows the greatest performance ranks for the majority of classification tasks. These days, ensemble learning is frequently utilised for more complex classifications in conjunction with a variety of classification algorithms for accurate prediction.

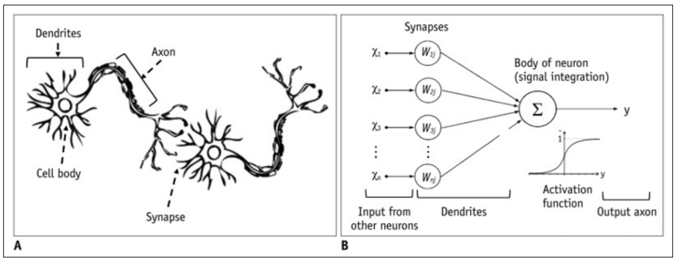

Figure 1: Conceptual analogy between real neurons (A) and artificial neurons [26].

The idea of neural networks inspired by biology is depicted in Figure 1. The components of a single neuron include the cell body, synapse, axon, and dendrites. The different input signals are integrated by the simple cell neuron and sent to additional neurons (Fig. 1A). Artificial neurons that are connected make up the ANN. Based on the weighted sum of the evidence, every artificial neuron executes a basic classifier (model) and gives a judgement signal as the output (Fig. 1B).

Deep learning (DL)

Deep learning meets the requirements of medical big data. It can be utilized to draw out all the helpful and beneficial understanding of the big medical data. This latest and current AI system can potentially provide preliminary radiological reports, propose differential diagnoses, and automatically discover lesions

Natural language processing (NLP)

Deep learning is employed for recognition of speech as well. It is done as a form of NLP (natural language processing). This includes applications such as recognition of speech, analysis of text, and in translation and other such purposes.

The growth, expansion, evaluation and categorization of medical records and studies (published ones) are the primary applications of NLP (natural language processing) in the healthcare sector. NLP networks and systems are competent enough to make a proper conversational AI, analysing those not so structured clinical notes on patients, and drafting reports like the ones on radiological exams. They are also capable of transcribing patient conversations [20].

In conclusion the types of AI technologies can be summarised as shown in the Figure 2. below:

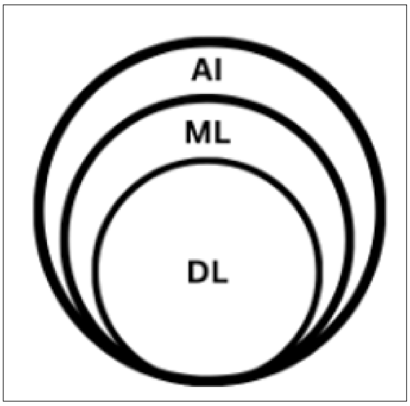

Figure 2: Schematic representation of the hierarchical relationship between AI, ML and DL

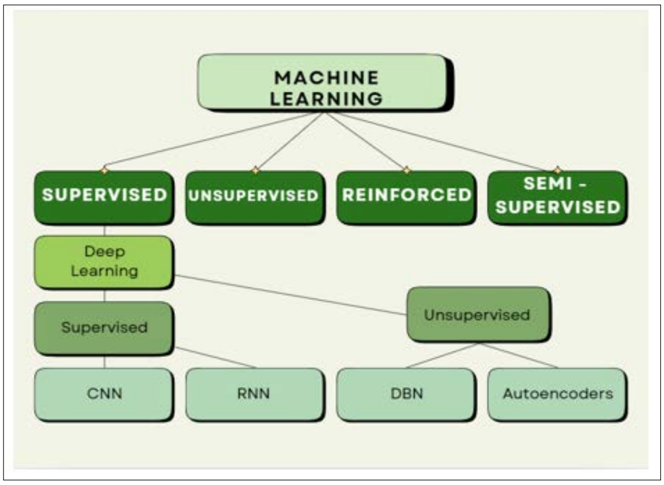

Figure 3: Simplified representation of the relationships between elements of AI.

Applications of AI in Medical Imaging

Detection and diagnosis of diseases (e.g., cancer, neurological disorders)

Artificial Intelligence (AI) has become a game-changer in the field of medical imaging, significantly altering how healthcare professionals interpret and analyse medical images to identify various diseases and conditions. By leveraging sophisticated machine learning algorithms and deep learning techniques, AI systems can process extensive volumes of imaging data swiftly and accurately, leading to earlier disease detection, more precise diagnoses, and ultimately, better patient outcomes [27].

A primary advantage of AI in medical imaging lies in its capacity to identify subtle abnormalities and patterns within medical images that may elude human detection. Whether it's X-rays, MRI scans, CT scans, or ultrasounds, AI algorithms excel in pinpointing lesions, tumours, fractures, and other disease markers with remarkable precision. The capability of such early detection of diseases allows for prompt interventions and proper planning of treatment which ultimately enhances and improves the prognoses and increasing rate of survival of patients [26].

Moreover, artificial intelligence-based systems are found to contribute as invaluable aids to radiologists and clinicians during the interpretation of not so simple imaging studies. By providing adequate measurements, differential diagnoses and risk assessments derived from the analysis of images, AI-driven diagnostic tools empower healthcare providers to make more informed decisions, minimize diagnostic errors, and customize treatement plans to suit individual patient needs. Also, AI streamlines workflow processes by prioritizing urgent cases and optimizing resource allocation within healthcare settings, resulting in more efficient and cost-effective patient care [17].

Furthermore, AI also bolsters screening programs and populations heath initiatives by automating the analysis of large – scale imaging datasets. This allows AI to identify at risk individuals and predict disease outcomes accurately, paving the way for targeted screening and preventive interventions. Such advancements reduce the burden of diseases like cancer, cardiovascular disorders, and neurological conditions.

AI has significantly contributed to the detection and diagnosis of various diseases, such as cancer and neurological disorders, by enabling more precise and earlier diagnoses. Researchers such as Saravanaprasad P have developed machine learning algorithms that effectively process and analyse medical images like CT scans, MRI and X rays, to identify early signs of diseases like lung cancer, brain tumours, and Alzheimer's disease [28]. These AI systems outperform traditional diagnostic methods in terms of speed and accuracy. For instance, in neurological imaging, Shanmugavadivel K, et al. [29] utilized deep learning models for Alzheimer's diagnosis, achieving notable success in analysing brain MRIs to predict the disease's progression.

Recent works by Ayyal et al. focused on AI-driven models for the early detection of Alzheimer's, leveraging multimodal imaging data [30]. Ayyal et al. also applied a hybrid deep learning model to predict Parkinson's disease from brain scans, marking a step forward in using AI for personalized diagnosis [30]. AI models have proven effective in diagnosing cardiovascular diseases through imaging techniques like echocardiograms and CT scans. Zhao J et al. demonstrated how AI could detect conditions like heart failure and arrhythmias from echocardiographic images, improving diagnostic accuracy and enabling early intervention [31]. Additionally, Zhao J et al. also used deep learning to analyse CT scans to plaque buildup and coronary artery disease, providing a more efficient and less invasive diagnostic tool [31].

During the COVID-19 pandemic, AI played a crucial role in early detection and risk assessment. Researchers like Ye J, [32] developed AI models to analyse chest X- rays and CT scans, helping to identify COVID-19 infections quickly. AI also supported global efforts by tracking virus spread, predicting hotspots, and optimizing resource allocation, ensuring timely interventions during critical moments of the pandemic. To develop and train these AI models, various public and proprietary datasets have been utilized. For example, the *LIDC-IDRI* dataset (Lung Image Database Consortium Image Collection) is a commonly used resource for lung cancer research, providing annotated CT scans. Similarly, datasets like *ADNI (Alzheimer's Disease Neuroimaging Initiative*) have been critical for training AI systems in the detection and progression analysis of Alzheimer's Disease (*Zhang W, et al*., 2023). [33] The *UK Biobank and Human Connectome Project* also offer large-scale neuroimaging datasets that researchers used to train models aimed at understanding neurological diseases such as Parkinson's and ADHD [34].

Image segmentation and annotation

Image annotation and segmentation can be defined as the process of classifying or labelling a virtual description or an image using annotation tools, text, or both, in order to create a set of corresponding labels for every image individually so as to train the DL and ML models. This is commonly implemented for object identification, boundaries and to segment images. These medical images are obtained from different imaging modalities. These include: Ultrasound, MRI, Mammography, CT scan etc., for ML and DL training [35].

Automatic image segmentation in the medical field plays a very important and critical role in medical care and scientific research. Deep learning methods generally depend upon quite a number of training datasets which includes annotations (manual) of high-quality that are tough to achieve in many such clinical applications. Here, we introduce AIDE (Annotation-Efficient Deep Earning) which is a framework (open-source) that is used to handle and manage not so perfect training datasets. Empirical evaluations and method wise analyses are conducted to demonstrate and show that AIDE surpasses fully-supervised conventional models as it presents better performance on datasets that are open which possess noisy or scarce annotations. Various annotation tools are used in this process, including VGG Image Annotator (VIA), LabelIMG, Ratsnake, Visual Object Tagging Tool (VOTT), Mask Editor, Supervisely, RectLabel, LabelMe, Computer Vision Annotation Tool (CVAT), LabelBox, ITK - SNAP and 3D slicer [36].

Workflow Optimization and Automation

Beyond its diagnostic uses, artificial intelligence (AI) has other significant applications in the electronic radiology process and the patient's journey through the healthcare system. These tools have the power to enhance productivity, boost efficiency, raise customer satisfaction, and improve quality and safety [5, 37-39].

Workflow gains more and more importance as the medical imaging department tries to maximise productivity [38, 39]. The analysis of every action that takes place within a single event is known as workflow.

In order to understand how workflow can be optimised to increase technologist efficiency, the imaging department's workflow optimization primarily focuses on automation and task consolidation, as well as the complicated relationship between information technology and radiologic technologists [37]. The importance of this relationship increases as more imaging departments switch from operating on film to operating without film [37].

The system gathers extensive invoice process data and implements processes like machine learning, process mining, and statistical analysis to determine workflow optimization opportunities. Then, by eliminating unnecessary stages, automating processes, modifying based on risk approval orders, and putting other improvements in place, it creates an enhanced target workflow [38]. Through a continuous feedback loop, the system can learn from its performance and get better over time.

The study of automatic algorithms that get better with use is known as machine learning [22,40]. Large biomedical data sets, or "big biomedical data," can be analysed and valuable insights can be extracted, leading to the advancement of biomedical research and better healthcare [38,39].

The user of a machine learning software tool usually has to manually choose a machine learning method and set one or more model parameters, also known as hyper-parameters, before a machine learning model is trained. The performance of the final model can be significantly influenced by the algorithm and hyperparameter values chosen, although doing so demands specialised knowledge and numerous labour-intensive human iterations [38].

Predictive Analytics and Prognosis

Artificial intelligence in medical imaging improves diagnostic capabilities and in addition to that also greatly contributes to predictive analysis and predictions.AI systems have the ability to evaluate not only historical but also real-time imaging data to predict the outcomes and the evolution of the disease via complex computational methods and machine learning algorithms. By using a predictive technique, healthcare providers may improve patient management and treatment and perform treatments on time [27].

AI in oncology may evaluate series imaging data to predict the growth and spread of tumours. AI systems are able to predict the chance of a chronic condition's progression or recurrence in patients. The treatment of chronic liver disorders is another use. AI is able to predict the development of liver fibrosis by examination of biochemical data. Doctors can postpone the growth of the tumours and enhance patients' results by recognizing people who are most likely to have chronic liver conditions and threat them early [17].

AI systems are able to predict the chance of a chronic condition's progression or relapse in patients. AI may also help oncologists in finding insights by combining these imaging trends with clinical information, especially genetic information, treatment purposes, and patient history. Making informed choices related to patient care, scheduling follow-up examinations and checkups, and modifying therapeutic plans are all made simpler with the use of the predictions made by AI [38].

Applications of AI in Neurological and Mental Diseases

AI has the potential in detection and diagnosis of neurological and mental disorders. By analysing complex brain images and understanding patient records, AI can help clinicians diagnose the disease which might get missed out in traditional methods. Some of the prominent diseases include Alzheimer's Disease, Parkinson's Disease, Major Depressive Disorder, Schizophrenia, Attention – Deficit/Hyperactivity Disorder and Autism Spectrum Disorder [41].

Alzheimer's Disease

Deep Learning Models have high value in identifying AD from various data sources, including limited to Brain MRI scans, retinal imaging, cognitive tests and sensor data, deciding about the disease progression, recognising biomarkers and drug targets, bettering clinical trials and care delivery. A recent study evolved a deep learning model which could identify AD risk from brain scans with greater than 90% accuracy [42].

AI models can scrutinise retinal pictures to help in A [43]. Studies show that AI can include cognitive evaluations, wearable sensors, and other sources, to identify AD in initial stages [44]. On the similar lines, Deep learning models can also be utilised to evolve personalised models of AD progression based on various parameters such as genetics, age and biomarkers so as to make accurate and individualistic treatment plans [45].

Researchers at West Virginia University used AI to unfold a set of metabolic biomarkers associated with AD risk [46]. AI can be useful in improving AD clinical trials by locating appropriate patient demographics, predicting results, and identifying adverse events much ahead of time. This method is less costly with more benefits and aids in identifying new treatments. Solutions assisted by AI can help clinicians in accurate diagnosis, disease progression monitoring, and rendering personalized care to AD patients. This is achieved through the use of AI chatbots that can provide assistance and education to patients and caregivers.

Parkinson's Disease

Artificial intelligence (AI) is increasingly being utilized in the field of Parkinson's disease (PD) for various applications that enhance diagnosis, monitoring, and treatment. Early Detection and Diagnosis is one among the applications in which an AI model developed for detecting PD. A model demonstrated high accuracy, with an area-under-the-cure of 0.9 for detecting this disease in a non-invasive way for assessment at home [9]. Researchers have achieved 96% accuracy in developing an AI tool which is capable of predicting the PD from blood samples which are up to 15 years before the onset of the first symptom. This tool analyses metabolites to identify biomarkers for early diagnosis, which could significantly improve patient care and management plans.

An AI system has been created to assess the motor performance of individuals with PD. Patients perform a finger tapping task in front of a webcam, and the AI tool generated measurements that match to the established guidelines. This AI tool can provide rapid diagnosis of PD, its severity, helping the doctors in improving care. The AI tools developed can be used for studies, allowing for the tracking of symptom progression over time. This capability is important for managing the episodic symptoms of PD and adjusting the treatment plans based on the actual data collected from the patients in their home environment. AI applications in PD assessment can bridge the gap in access to neurological care. By enabling remote assessments, patients need not travel for clinic visits as they get the required evaluation done easily by AI. This in turn also helps in enhancing health of the patient. The methodologies developed for assessing PD severity can be adapted for other movement disorders, such as ataxia and Huntington's disease. This versatility opens new doors for using AI in various neurological conditions.

Major Depressive Disorder

Models in AI can examine brain MRI and fMRI scans to recognize various patterns indicative of MDD, often with great accuracy. For example, a study developed an AI model that could discover MDD risk from brain MRIs with 75-85% accuracy. Merging resting-state EEG and single-pulse transcranial magnetic stimulation (TMS)-evoked EEG indices, an AI system achieved high discriminative accuracy in determining MDD. Integrating brain imaging, clinical data, and other biomarkers, AI models can foresee MDD with enhanced performance in contrast to utilizing discrete data types.

AI is being employed to anticipate how people with MDD will respond to specific antidepressant medications. A machine learning algorithm was 75-85% accurate in predicting whether common antidepressants would work for specific MDD patients in a preliminary study. Multimodal machine learning approaches, operating brain imaging and clinical data, can accelerate the project antidepressant efficacy, potentially allowing for more personalised treatment plans. AI can help optimize MDD clinical trials by pinpointing the right patient populations, predicting outcomes, and detecting adverse events earlier. This can reduce costs and accelerate the development of new treatments.

Attention Deficit/Hyperactivity Disorder (ADHD)

Promising results have been observed in the detection of ADHD from a variety of data sources using AI models, including machine learning and deep learning algorithms. AI models can identify patterns indicative of ADHD from brain MRI, fMRI, and EEG data. For example, a study created an AI model that has a 75-85% accuracy rate in identifying ADHD risk from brain MRIs [47]. AI language models have the ability to identify minute patterns in the speech of people with ADHD, which may be useful for diagnosis and evaluation. According to a recent study, compared to healthy controls, ADHD sufferers' spontaneous word recall was less predictive by an AI language model [47].

Using extensive electronic health records, AI systems have been utilised in some studies to predict the start of ADHD with extremely high accuracy [47]. AI is being used to forecast how people with ADHD will react to particular drugs. The utilization of AI techniques to enhance the analysis of motor information is crucial in expanding our comprehension and enhancing the treatment of ADHD. A more complex understanding of ADHD is made possible by the incorporation of AI methods, such as machine learning and data analysis, into research on motor behaviours associated with the illness. This method makes it easier to spot the patterns and abnormalities in motor activity that are frequently indicative of ADHD, which helps with more accurate diagnosis and specialised treatment plans.

Autism Spectrum Disorder (ASD)

Autism Spectrum Disorder (ASD) is a neurodevelopmental condition characterized by challenges in social communication, restricted interests, and repetitive behaviours. Symptoms often emerge in early childhood and vary widely across individuals, ranging from mild difficulties in social interaction to severe cognitive and behavioural impairments. The complexity of ASD diagnosis arises from overlapping symptoms with other disorders, such as ADHD, and its highly individualized manifestations [48].

Medical imaging, particularly MRI, has become crucial in identifying brain structure and functional abnormalities associated with ASD. Structural MRI (SMRI) highlights changes in grey matter volumes and the cerebellum, while functional MRI (fMRI) maps brain activity and connectivity patterns. Machine learning (ML) and Deep Learning (DL) techniques have been integrated with these imaging modalities to identify biomarkers for ASD, enhancing diagnostic accuracy. Resting – state fMRI (rs – fMRI), for example, reveals disrupted connectivity in regions linked to social and cognitive functions, aiding in early diagnosis [49,50].

AI – based methods, including ML and computer – aided diagnosis (CAD) systems, analyse complex imaging patterns, identifying interdependencies between brain regions that traditional statistical techniques may overlook. These tools offer a low – cost, scalable approach to ASD diagnosis, complementing clinical evaluations. However, challenges persist in translating research finding into clinical practice due to variability in symptoms and the diverse ethology of ASD. Emerging studies highlight the potential of multimodal approaches that combine imaging, behavioural analysis, and genetic data to refine ASD diagnosis and tailor interventions effectively [51].

Table 1: Comparative table of AI Applications in the Diagnosis and Treatment of Neurological and Mental Disorders

Disease/Disorder	AI Methodology	Applications/Advancement	Key Insights
Alzheimer's Disease	Deep Learning with Neuroimaging. AI models for retinal image analysis [42].	AI models are used to identify risk, biomarkers, and disease progression from data source like brain MRI, retinal imaging, cognitive tests, and sensor data. AI helps in clinical trials, drug discovery, and personalized treatment plans.	Detection of subtle biomarkers, improved early intervention strategies
Parkinson's Disease	Neural Language Processing (NLP), EEG, Machine Learning. AI motor performance assessment using webcam.	AI enhances early detection, motor performance assessment, and disease monitoring. AI tools can predict PD from blood samples and assess severity through non – invasive motor tasks using webcams. Remote assessment improves access to care.	Objective diagnosis using linguistic and brainwave – based features.
ADHD	Support Vector Machines (SVM), EEG Analysis [47]	AI is used to identify ADHD patterns in brain MRI, fMRI, EEG, and through language analysis. Machine learning tools are also used to predict ADHD onset from electronic health records. AI techniques improve motor behaviour analysis for diagnosis.	AI tools facilitate personalized treatment planning based on neural activity
Autism Spectrum Disorder (ASD)	Machine learning (ML), Random Forest, XGBoost, AI – based CAD [49-51]	AI driven medical imaging (MRI, fMRI) helps detect structural and functional brain abnormalities. AI techniques like machine learning and deep learning helps in early diagnosis and monitoring of ASD. Multimodal approaches combine imaging and behavioural data.	Caregiver stress predictors assist in improving patient and caregiver outcomes

Major Depressive Disorder (MDD)	AI model for brain MRI analysis in MDD and antidepressant efficiency prediction.	AI is used for identifying patterns in brain scans, EEG, and clinical data for diagnosing MDD. AI models can predict patient responses to antidepressants and optimize clinical trials by pinpointing the right patient demographics.	Predict treatment responses and optimize clinical trials by identifying right patient groups and detecting adverse events early.

Benefits of AI in Medical Imaging

The area of medical imaging is undergoing a significant change on account of the use of AI. One of the main factors is the phenomenal improvement in the time in which the analysis is carried out. Age-old ways of reading and understanding medical images like X-rays, CT scans, and MRIs are very time taking ways. They result in delays in diagnosis and also could be subjective due to human error. On the other hand, AI can diagnose such at a rapid fast pace resulting in faster diagnosis. This helps the healthcare professionals to begin the treatment sooner and thereby resulting in increased possibilities of saving lives under critical conditions. Additionally, AI scrutinises the images religiously for even very minute possible abnormalities.

Apart from the swiftness in the diagnosis, AI ensures remarkable accuracy in diagnosing diseases. AI algorithms have a tremendous ability to identify trends, patterns and anomalies that might get missed out when looked at by the human eye. This becomes possible on account of training the AI on vivid and voluminous datasets of medical images. This leads to a massive reduction in wrong diagnoses and ensures that the patients receive adequate treatment as soon as possible. An early detection and commencement of treatment is essential for improving patient outcomes particularly in fatal diseases like cancer as in such cases the stage at diagnosis has a larger impact on detection and treatment thereof. AI permits the healthcare professionals to detect the diseases much ahead of time, thereby ensuring more effective treatment and improved patient well-being (academia.edu).

The impact of AI is also seen in personalised medicine. By analysing a patient's personal medical history and unique characteristics, AI can suggest meaningful insights into various available treatment options. This empowers healthcare professionals to create individualised plans of treatment that address the individual needs of each patient. This personalised approach has the ability to drastically improve patient care and that leads to improved treatment results and a comprehensive healing experience [52].

Challenges and Limitations

Challenges in biomedical imaging include achieving faster acquisition speeds and reducing radiation doses. The substantial volume of imaging data necessitates advanced informatics for storage, transmission, analysis, and automated interpretation, highlighting the importance of big data science in enhancing diagnosis and utilisation [26].

The application of artificial intelligence (AI) in medicine faces hurdles like limited dataset availability for training and validation due to non-standardized electronic medical records and stringent privacy laws. Although harmonised data formats like DICOM (Digital Imaging and Communications in Medicine) aid in data exchange, privacy preservation remains critical. The high cost of electronic patient data management can exclude hospitals in less privileged areas from participating in studies, reinforcing issues of bias and fairness [53].

In medical imaging, DICOM is universally adopted, and digital storage is common, facilitating data sharing and remote access. Privacy laws such as HIPAA (Health Insurance Portability and Accountability Act) and GDPR (General Data Protection Regulation) enforce strict controls over health data, emphasising the need for secure data handling and AI governance. AI in medical imaging raises ethical concerns regarding patient privacy and data security, necessitating robust measures to prevent unauthorised access and ensure compliance with privacy regulations. Transparent communication and informed consent about AI usage in patient care are also crucial [26, 54].

AI success in medical imaging hinges not only on large datasets but also on accurate data labelling by trained professionals. International variations in data protection laws and restrictions on data movement pose significant challenges to the generalisation and clinical application of AI. An interconnected network of patient datasets is essential for AI to be robust and generalised across different demographics and regions [53].

Currently, there is no official regulatory framework for integrating AI into clinical practice. Artificial Intelligence models must engage in rigorous testing and give an idea of high sensitivity and specificity to ensure the safety of the patient. The possibility of unethical practices by private sector developers and high false positive rates remains major barriers to the universal adoption of AI in healthcare.

AI has shown great applications in Alzheimer's disease and Parkinson's disease, including early diagnosis, treatment optimization, and patient monitoring. However, there are some challenges that need to be addressed to fully realize its benefits. Research on both diseases often relies on small datasets due to the difficulty in obtaining large, high – quality datasets. This can lead to models that are not generalizable. Many AI applications in PD rely on data from wearables and sensors to monitor symptoms. The quality and consistency of this data can be variable. Also, variability in data due to different imaging protocols, demographic diversity, and clinical settings can affect model performance. Accurate labelling and annotation of data (e.g., brain images, clinical notes) are crucial but time consuming and require expert knowledge [55].

Additionally, protecting patient data privacy is critical, especially given the sensitive nature of medical information. AI models can inadvertently perpetuate biases present in the training data, leading to disparities in diagnosis and treatment recommendations. Ensuring that patients understand how their data will be used for AI development is necessary for ethical practice [56]. Effectively analysing and integrating longitudinal data to track disease progression and treatment responses over time are complex. Developing and implementing AI systems can be expensive, and healthcare providers may face financial barriers in adopting these technologies [57].

Moreover, many AI models, especially deep learning models, are often seen as "black boxes." Understanding how they make decisions is crucial for clinical acceptance and trust [58].

Addressing these challenges requires a concerted effort from researchers, clinicians, policymakers, and technology developers to ensure that AI can effectively contribute to the understanding, diagnosis, and treatment of Alzheimer's disease. AI might encourage prejudice and discrimination against people who have ADHD. The development processes usage of training data and algorithms may be the cause of this. For example, the AI model might perform poorly for people from marginalized communities if the training data mostly consists of ADHD sufferers from a particular socioeconomic class, racial group, or geographic area. This is because the AI model may not be sufficiently representative to deal with a range of demographics.

While apps which use AI are used to study people's everyday activities and movement patterns in order to identify symptoms of ADHD and help them stay organised, privacy and identity concerns may arise. Sensitive personal data, including location data, medical history, daily interactions, choices and actions, may be collected by these apps. This information could be shared or exploited without the required authorization. Concerns about ADHD identification may also arise from the expected outcomes of AI systems being unclear and hard to understand. It can be challenging for human clinicians to comprehend why the model produced a specific result. Transparency and interpretability of the AI model in ADHD can be enhanced by incorporating clinicians'; input into the decision-making process and by offering explanations and visualisations based on a knowledge graph [59]. Major Depressive Disorder or MDD in short puts forward various challenges and limitations

which only complicates its diagnosis, treatment, and management. In many cases, MDD fails to be accurately recognized owing to its overlap with other mental health disorders which only leads it up to potential underdiagnosis or misdiagnosis.

Moreover, the stigma associated in society with respect to mental health further worsens this issue as it discourages individuals from seeking necessary help at the correct time. It also depends heavily upon the inputs given by patients and their reported symptoms only adding to the complexity of its subjective nature. Treatment resistant depression is another main issue wherein patients do not give a response to standard antidepressants. This in turn results in side effects of these medications only leading the patient to poor response to treatment and contributing to other health based problems in individuals. Another aspect of this is that the disorder differs with each human being. To counter this, a personalised approach is required. Furthermore, the societal and economic impacts are intense and cannot be ignored. Expensive healthcare, decrease in productivity, and overall affected quality of life for affected individuals are other such challenges.

Latest Developments in AI in Medical Imaging Analysis

Neuroimaging has been profoundly transformed by advancements in artificial intelligence (AI), which have enhanced the accuracy, speed, and insights derived from imaging data. These innovations are pivotal in diagnosing, monitoring, and understanding neurological and mental disorders such as Alzheimer's disease, schizophrenia, Parkinson's disease, and autism spectrum disorders.

AI has significantly improved the analysis of structural and functional neuroimaging modalities such as magnetic resonance imaging (MRI), functional MRI (fMRI), positron emission tomography (PET), and electroencephalography (EEG). Deep learning algorithms, particularly convolutional neural networks (CNNs) and recurrent neural networks (RNNs), now automate tasks like lesion detection, brain volume quantification, and functional connectivity analysis. For instance, AI-based MRI analysis has facilitated the early detection of Alzheimer's disease by identifying subtle structural changes in brain regions like the hippocampus and entorhinal cortex, which are affected in the initial stages of the disease. Similarly, fMRI data processed using deep learning enables the identification of disrupted functional connectivity patterns associated with conditions such as schizophrenia and bipolar disorder, providing more reliable biomarkers for these complex diseases [60]

One of the most groundbreaking applications of AI in neuroimaging is its use in analysing multimodal imaging data. Combining information from modalities like PET and MRI offers a more comprehensive understanding of brain pathology. AI facilitates this integration by aligning and processing data from different imaging techniques, which is particularly valuable for understanding neurodegenerative diseases like Parkinson's and Huntington's. Studies demonstrate that PET-MRI fusion guided by AI can better characterize dopaminergic deficits in Parkinson's patients, aiding in early diagnosis and monitoring disease progression [61,62].

Explainable AI (XAI) has also gained attraction in neuroimaging, addressing a critical need for transparency in AI-driven decision-making. By highlighting regions of interest in brain scans or providing visual explanations of algorithmic predictions, XAI tools have improved trust among clinicians. For example, saliency maps and other interpretability tools have made it possible to visualize abnormal brain activity patterns associated with disorders like epilepsy, enhancing the accuracy of surgical planning for resecting seizure-causing brain tissue [63].

AI's role extends to advancing research on mental health disorders, where it is used to analyse large-scale neuroimaging datasets. For instance, machine learning models have identified biomarkers linked to depression and anxiety by analysing functional connectivity patterns in resting-state fMRI data. These biomarkers not only provide insights into the neural underpinnings of these conditions but also serve as predictors for treatment response to therapies such as cognitive behavioural therapy (CBT) or pharmacological interventions [64,65].

In autism spectrum disorders, AI has been instrumental in identifying atypical brain connectivity and structural variations that underlie the condition. Advanced neuroimaging analysis using AI has uncovered critical differences in white matter integrity and cortical thickness in individuals with autism. This has improved early diagnosis and provided a better understanding of how neurodevelopmental trajectories diverge in affected individuals [31,66].

Future Perspective of AI in Medical Imaging

Operation of artificial intelligence in the field of medical imaging is going to make considerable progress in the years to come and they possess a far-reaching potential in a broad range of applications. Medical image analysis is much more faultless and systematic and structured in today's times. This is done by including various algorithms and networks such as DLAs (deep learning algorithms) like GANs (generative adversarial networks) and CNNs (convolutional neural networks). These developments make it possible to precisely and quickly identify anomalies in radiological exams and retinal images, such as tumours and early disease indicators [17].

The execution of generative AI models in medical imaging (like transformers and GANs), is a prominent trend in the study. Running of these models is very beneficial as these models are exceptionally good in various activities such as picture synthesis that call for and require a high degree of precision, detail and accuracy. This is because of the application of specific techniques like SPADE (Spatially-Adaptive (DE) normalisation) which guarantees the production of varied, high-quality and realistic medical images [67].

Radiology, pathology, and cardiology are some fields experiencing a practical impact of AI in Medical Imaging. It has been demonstrated that AI-based diagnostic tools greatly help to the interpretation of complicated images, assisting in the early detection of disease and enhancing patient outcomes. AI systems, for example, can improve the early diagnosis of diseases like lung cancer and diabetic retinopathy, enabling prompt therapies that can save lives [38, 68-73].

Conclusion

AI in medical imaging has transformed the healthcare sector to a great extent. Whether it is diagnostic accuracy, efficiency or personalised patient care, AI in medical imaging has proved to be of significant use. Various different technologies such as machine learning, deep learning and natural language processing have helped in disease detection, image segmentation and workflow optimization. These developments not only enhance the precision and speed of medical image analysis but also help in disease detection and treatment planning thereby improving patient outcomes.

Although there are ample benefits of AI in medical imaging, it faces several challenges such as limited dataset availability, strict privacy laws, and the high cost of data management. Also, the need for accurate data labelling, ethical concerns regarding patient privacy, and the absence of standardised regulatory frameworks are critical issues that must be ensured for safe execution of AI in the healthcare sector.

Looking forward, the future of AI in medical imaging looks highly promising. It has already helped medical professionals a lot and will continue to do so. Advances in deep learning algorithms, generative AI models, and other innovative techniques are expected to further enhance the accuracy and efficiency of medical image analysis. As technology evolves, it becomes evident that AI has the potential to improve patient care up to great extent.

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