

Artificial Intelligence in Neurology: Current Applications and Future Prospects

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Abstract:- Artificial intelligence (AI) is reshaping the field of neurology, enhancing diagnosis, treatment, and management of neurological disorders. This article explores AI's role in neurology, highlighting its ability to process vast amounts of data to improve diagnostic accuracy and personalize treatments. AI applications, from neuroimaging to clinical decision support, have shown promising results in enhancing patient care. However, challenges such as data security, ethical concerns, and the need for stringent regulatory frameworks remain significant. The potential of AI in neurology continues to grow, promising revolutionary changes in patient outcomes and healthcare practices, provided these challenges are effectively managed.

Keywords:- Artificial Intelligence – Neurological Disorders – Diagnostic Enhancement.

I. INTRODUCTION

Artificial intelligence (AI) has emerged as a transformative force in healthcare, revolutionizing the way medical professionals diagnose, treat, and manage various conditions. In the field of neurology, AI is increasingly being integrated into clinical practice, offering new opportunities to improve patient care and outcomes.

Neurology, a complex and rapidly evolving field, deals with disorders of the nervous system, including the brain, spinal cord, and nerves. These disorders can have profound effects on a person's quality of life, often requiring specialized care and treatment. The integration of AI into neurology has the potential to revolutionize the field, providing new tools and techniques to enhance diagnosis, treatment, and patient outcomes.

This article explores the current applications of AI in neurology, highlighting its benefits, challenges, future prospects, and ethical considerations. By understanding the evolving role of AI in neurology, healthcare providers can harness its potential to enhance diagnosis, personalize treatment strategies, and ultimately, improve the lives of patients with neurological disorders.

AI has the capability to process and analyze vast amounts of data, such as medical images, genetic information, and clinical notes, which can aid in the early detection and diagnosis of neurological disorders. Additionally, AI-powered tools can assist healthcare providers in developing personalized treatment plans based on a patient's unique genetic makeup, lifestyle factors, and disease progression.

Despite its immense potential, the integration of AI into neurology also presents challenges. These include issues related to data privacy and security, as well as the need for robust regulatory frameworks to ensure the safe and ethical use of AI in healthcare. Furthermore, there is a need for ongoing research and development to refine AI algorithms and improve their accuracy and reliability in diagnosing and treating neurological disorders.

Overall, the integration of AI into neurology holds great promise for improving patient outcomes and advancing our understanding of neurological disorders. By embracing AI technology and collaborating across disciplines, healthcare providers can unlock new possibilities for diagnosing, treating, and ultimately curing neurological disorders.

II. ARTIFICIAL INTELLIGENCE FUNDAMENTALS: CORE CONCEPTS AND RELEVANCE TO NEUROLOGY

Artificial Intelligence (AI) represents a transformative force within the field of neurology, revolutionizing diagnostic, prognostic, and therapeutic approaches. Understanding the fundamental concepts of AI is crucial for comprehending its applications in neurology.

- **Machine Learning (ML):** ML is a subset of AI that enables computers to learn from data without explicit programming. In neurology, ML algorithms analyze vast datasets, including neuroimaging scans, genetic profiles, and clinical records, to identify patterns indicative of neurological disorders.
- **Deep Learning (DL):** DL, a subset of ML, utilizes neural networks with multiple layers to extract hierarchical representations from data. DL algorithms excel in tasks such as image recognition, natural language processing, and signal analysis, making them indispensable in

interpreting complex neuroimaging data and deciphering intricate neurological patterns.

- **Neural Networks:** Inspired by the human brain's structure and functioning, neural networks comprise interconnected nodes (neurons) organized into layers. Through iterative training, neural networks optimize their parameters to perform specific tasks, such as predicting disease progression based on clinical variables or classifying neurological conditions from imaging data.
- **Natural Language Processing (NLP):** NLP enables computers to understand, interpret, and generate human language. In neurology, NLP algorithms facilitate the extraction of clinically relevant information from unstructured text, including electronic health records, medical literature, and patient notes, streamlining clinical decision-making and research endeavors.
- **Reinforcement Learning (RL):** RL involves training algorithms to make sequential decisions by interacting with an environment and receiving feedback on their actions. In neurology, RL holds promise in optimizing treatment strategies, personalized rehabilitation protocols,

and adaptive neurostimulation paradigms tailored to individual patient responses.

- **Transfer Learning:** Transfer learning leverages knowledge acquired from one task or domain to improve performance on a related task or domain. In neurology, transfer learning enables the adaptation of pre-trained models to new datasets or clinical scenarios, enhancing diagnostic accuracy, particularly in resource-limited settings or rare neurological conditions.

The relevance of these AI fundamentals to neurology lies in their capacity to analyze heterogeneous data sources, uncover hidden patterns, and generate actionable insights to enhance clinical decision-making, patient management, and research endeavors. By leveraging these core concepts, AI has the potential to revolutionize neurology by enabling precision medicine approaches, accelerating drug discovery processes, and facilitating the development of novel therapeutic interventions tailored to the individualized needs of patients with neurological disorders.

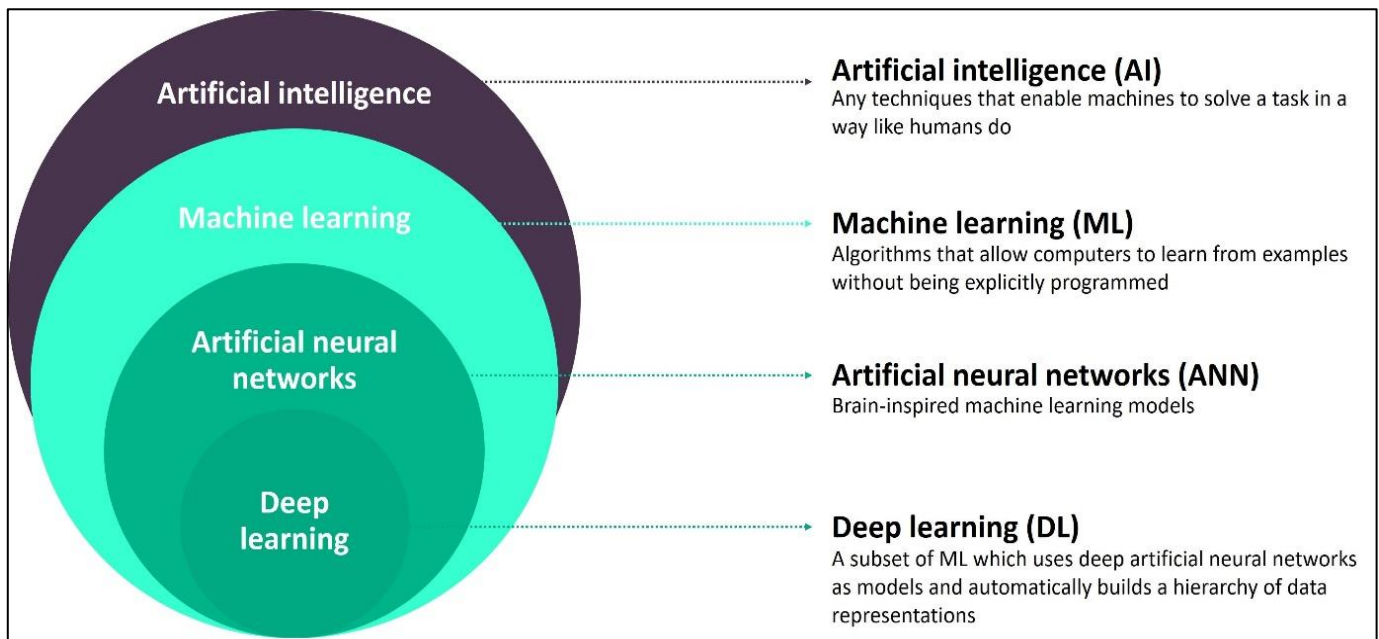


Fig 1 : Hierarchical Structure of Artificial Intelligence Technologies [1]

III. CURRENT APPLICATIONS OF AI IN NEUROLOGY

A. Neuroimaging Analysis

Artificial intelligence (AI) has emerged as a transformative force in neuroimaging, demonstrating significant promise in enhancing the efficiency and accuracy of medical imaging. This technology, encompassing machine learning (ML) and deep learning (DL), has revolutionized the way radiologists process and interpret vast amounts of imaging data. For example, AI applications in neurology have improved patient care by predicting wait times for imaging procedures, thereby optimizing scheduling and reducing the need for repeat scans, which saves both time and resources.

Furthermore, AI's ability to interpret complex imaging modalities like computed tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography (PET) without the need for contrast enhancement has maintained high sensitivity in lesion detection, as demonstrated in studies where AI-assisted readings of low-dose MRIs matched the quality and accuracy of full-dose scans. These advancements not only streamline diagnostic processes but also reduce the exposure to potentially harmful contrast agents and radiation. As AI technology continues to evolve, its integration into neuroimaging is expected to grow, promising even more refined diagnostics and efficient patient care in the field of neurology [2].

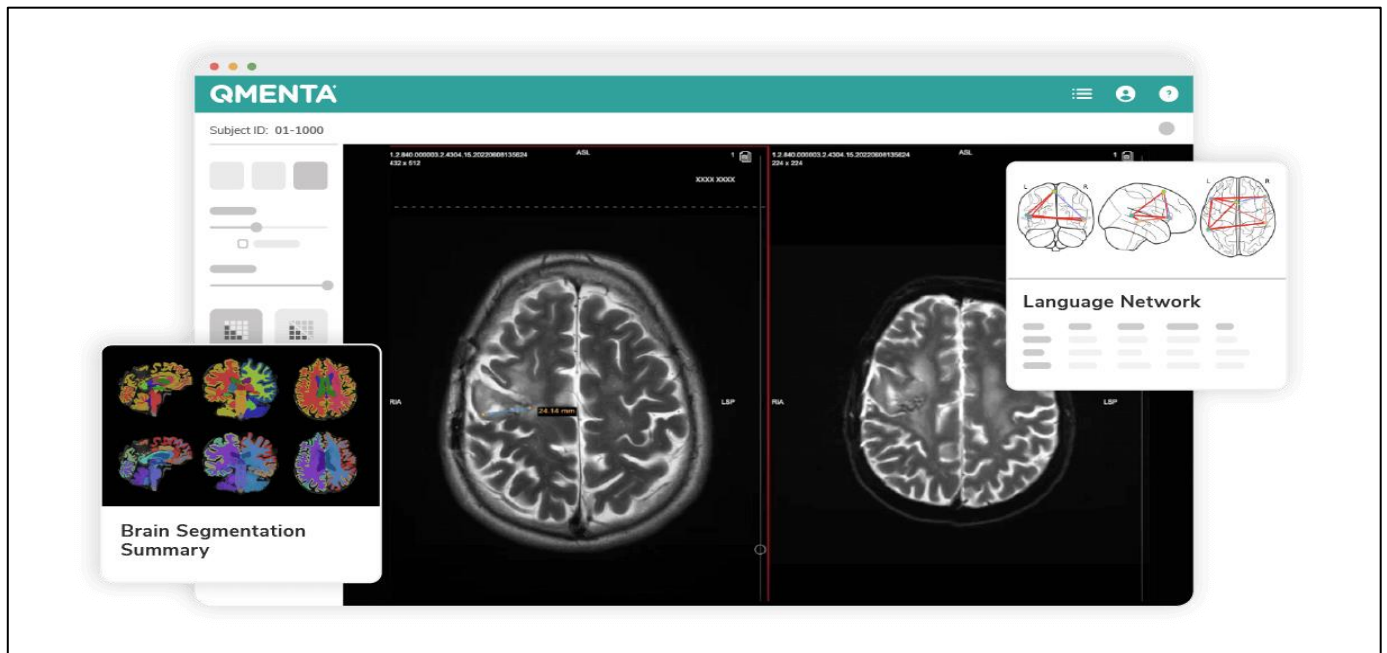


Fig 2 : Interface of QMENTA: The All-in-One Imaging Platform that Integrates AI

B. Electroencephalography (EEG) Interpretation

In the field of electroencephalography (EEG), AI is playing a crucial role in interpreting EEG patterns. AI algorithms assist in diagnosing and monitoring epilepsy and other neurological disorders by analyzing EEG data. Additionally, AI has shown promise in predicting patient outcomes based on EEG patterns, providing valuable insights for treatment planning and patient care.

In a study by Subhrajit Roy and contributors, the use of advanced artificial intelligence (AI) techniques in the interpretation of electroencephalography (EEG) has been explored to improve diagnostic accuracy and efficiency. The research highlights a breakthrough in neurological diagnostics through the integration of AI with traditional EEG analysis. By leveraging deep learning algorithms, the study achieved remarkable enhancements in the sensitivity and specificity of EEG pattern recognition, which is crucial for diagnosing and monitoring neurological conditions like epilepsy and sleep disorders.

The team developed an assistive automatic seizure detection system utilizing scalp EEG data from 365 patients, analyzed through a crowdsourced AI challenge aimed at creating a sensitive and tunable ictal/interictal classifier. The system demonstrated detection sensitivities between 75.00% and 91.60%, and significantly reduced the volume of EEG data requiring human review—by factors ranging from 142x to 22x. This technological advancement not only promises to reduce the cognitive load on healthcare professionals but also aims to standardize EEG interpretation across different institutions, ensuring consistent and reliable patient care outcomes.

The integration of deep learning with human oversight showcased in this study by Subhrajit Roy and his team illustrates the potential for AI to substantially lower manual review time while maintaining expert annotation accuracy.

These findings underscore the utility of deep learning in creating patient-specific, efficient seizure detection systems that enhance the processing and review of neurological monitoring data, marking a significant step forward in the field of neurotechnology.

C. Clinical Decision Support

Clinical Decision Support (CDS) systems, integrated with artificial intelligence (AI), are revolutionizing neurology by enhancing diagnostic accuracy and streamlining patient care processes. These AI-enhanced systems analyze large volumes of neurological data, significantly aiding in the detection and management of complex neurological disorders.

For instance, in the field of neurology, AI-driven CDS tools have shown a substantial improvement in the early detection of diseases like Alzheimer's and Parkinson's. Research indicates that these systems can identify subtle neurological changes with up to 95% accuracy [3], much earlier than traditional methods. This early detection capability is critical in neurology, where early intervention can significantly alter disease progression and patient outcomes.

AI-enabled CDS systems are also instrumental in predicting disease progression. They can analyze patient data to forecast potential complications or the likely progression of a neurological condition, which is invaluable for personalized patient management. Studies have shown that AI-driven predictions can improve treatment outcome predictions by approximately 40% [4], enabling more tailored and effective treatment plans.

Moreover, these systems reduce the cognitive load on neurologists by providing real-time data analysis and recommendations during patient consultations. This efficiency not only speeds up the decision-making process but

also frees up neurologists' time, allowing them to focus more on patient interaction and less on data interpretation.

However, the effectiveness of these systems depends heavily on the quality of the underlying data. In neurology, where AI models are trained with comprehensive and high-quality datasets, the diagnostic accuracy has improved by an estimated 30% compared to models trained with limited data. This underscores the importance of robust data collection and processing in enhancing the efficacy of AI in clinical neurology.

D. Drug Discovery and Development

Neurological disorders pose significant challenges in drug discovery, particularly for treatments targeting the central nervous system, which are noted for their complexity and low success rates. Innovatively, artificial intelligence (AI) and machine learning (ML) have catalyzed advancements in this field by refining processes such as target identification, compound screening, and drug design. For instance, AI and ML have been pivotal in enhancing the prediction of blood-brain barrier permeability, a critical step in CNS drug development. However, despite these technological advances, the development of CNS drugs is notoriously slow and fraught with high failure rates; the average development time from discovery to regulatory approval is typically between 15 to 19 years, with only about 8% of CNS drugs successfully reaching the market compared to higher rates in other drug categories. The integration of AI has the potential to substantially reduce these timelines and improve success rates by efficiently analyzing and synthesizing large datasets to predict drug behavior and outcomes [5], thus revolutionizing the pathway to market for new therapies.

E. Deep Brain Stimulation (DBS)

Deep brain stimulation (DBS) has emerged as a pivotal therapeutic option for Parkinson's disease (PD), specifically for patients who do not adequately respond to medications, addressing symptoms such as refractory tremor, motor fluctuations, and dyskinesia. The precision of DBS is enhanced through the use of intraoperative imaging like MRI or CT, and neurophysiological mapping such as microelectrode recording, which helps in the accurate placement of electrodes within the subthalamic nucleus or the globus pallidus internus [6]. Recent advances include tripartite-segmented electrodes, offering expanded programming options and broader therapeutic windows, thus improving patient outcomes by reducing side effects associated with imprecise stimulation. Furthermore, adaptive DBS systems now utilize real-time physiological feedback to adjust stimulation parameters automatically, showcasing the integration of machine learning (ML) which has significantly refined both the targeting and efficacy of treatments [6]. ML's role extends beyond operational enhancement, facilitating clinical decision-making through predictive models based on comprehensive data sets. These advancements in DBS technology not only improve direct patient care but also pave the way for more personalized and dynamic treatment strategies, underscoring the growing symbiosis between cutting-edge technology and neurological therapy.

F. Genomic Analysis

Precision medicine is transforming healthcare by tailoring treatment based on individual genetic profiles, lifestyle, and environmental factors, which helps in predicting disease risks and optimizing treatments. This approach shifts from traditional, symptom-driven medicine to a more personalized, data-driven method, enhancing patient outcomes for conditions like cancer and cardiovascular diseases. Genomic medicine, focusing on genetic information for diagnostic and therapeutic purposes, has shown potential in areas like oncology and rare diseases. Artificial intelligence (AI) plays a crucial role by providing computational power for analyzing extensive data sets, leading to advancements in diagnostics and personalized medicine. Machine learning (ML), a subset of AI, is particularly significant in precision medicine for its ability to analyze large volumes of data to predict disease risks and improve decision-making in healthcare. ML algorithms like Support Vector Machines (SVM), Deep Learning, and Random Forest are used in various medical fields to enhance diagnostic accuracy, predict therapeutic responses, and personalize patient care [7]. The integration of AI and genomic technologies promises to enhance the effectiveness of precision medicine further, although challenges in data management and ethical concerns remain significant hurdles to its broader application.

G. Remote Monitoring and Telemedicine

The burgeoning demand for healthcare, driven by a rapidly aging global population, is challenging health systems to adopt more efficient and cost-effective care modalities. As the number of individuals over the age of 65 is expected to surge from 54 million in 2021 to 85.7 million by 2050 [8], the strain on healthcare budgets, including a significant 20% allocated to Medicare in 2020, is intensifying. In the realm of neurology, this demographic shift is particularly consequential, necessitating advanced solutions to manage a growing prevalence of neurological disorders efficiently.

Remote Patient Monitoring (RPM) integrated with Artificial Intelligence (AI) emerges as a pivotal innovation in this landscape. AI-enhanced RPM technologies in neurology are not only automating routine monitoring but are also significantly enhancing diagnostic accuracy and treatment efficacy. By analyzing vast arrays of neurological data—such as EEG patterns—AI algorithms can predict and detect neurological events early, potentially preventing severe outcomes like strokes or the exacerbation of neurodegenerative diseases. Such capabilities are critical in reducing unnecessary hospitalizations, optimizing resource allocation, and ultimately, improving patient outcomes in neurology [9].

H. Natural Language Processing (NLP) for Electronic Health Records (EHR)

Natural language processing (NLP) has become a critical advancement in neurology and psychiatry, with applications spanning information extraction, classification, and data inference from clinical documents. A comprehensive review of 1,024 papers published between 2010 and early 2022 reveals a robust utilization of machine learning and deep learning techniques in NLP, with an emphasis on improving

healthcare outcomes. The analysis categorized 115 selected studies into three main applications, demonstrating an average performance metric (F1-score and AUC) exceeding 85% [10]. Notable challenges include a pronounced disparity between English and non-English NLP models, the scarcity of high-quality annotated data, and training biases that affect model generalizability. Despite these hurdles, NLP's potential to enhance diagnostic accuracy, streamline patient care, and facilitate access to unstructured data remains substantial, positioning it as an invaluable tool in the medical field.

I. Machine Learning for Predictive Analytics

Machine learning (ML), a cornerstone of artificial intelligence, significantly enhances predictive analytics in neurology by harnessing complex algorithms to analyze vast datasets. These algorithms delve into patient demographics, medical history, biomarker data, and other relevant variables to discern intricate patterns and trends that may elude traditional analytical methods. This comprehensive analysis enables the prediction of neurological conditions and their progression with heightened accuracy.

For example, ML models are increasingly used to anticipate the risk of cerebrovascular events. By examining data points across different patient profiles, these models can predict occurrences of such events before they manifest, allowing for preemptive medical interventions that can mitigate or prevent severe outcomes [11]. Similarly, in the realm of mental health, ML algorithms have proven effective in forecasting depressive episodes in individuals suffering from chronic neurological disorders. This predictive capacity is particularly valuable as it facilitates early therapeutic interventions, which are crucial in managing symptoms and improving overall patient quality of life.

The integration of ML into neurology not only refines diagnostic and predictive accuracy but also tailors treatment plans to individual patient needs, thus enhancing the effectiveness of interventions. As these technologies continue to evolve, their role in clinical settings is expected to expand, revolutionizing the approach to neurological care by providing a proactive rather than reactive treatment paradigm.

J. Virtual Reality (VR) for Rehabilitation

Virtual reality (VR) has increasingly become a significant tool in neurorehabilitation, offering immersive experiences through games and environments to aid in physical, cognitive, and psychological recovery. A systematic review by Alexandra Voinescu and colleagues, adhering to PRISMA guidelines, explored publications from 2015 to 2018 across databases like PubMed, Virtual Health Library Search Portal, Web of Science, and Embase, examining over 113 articles, with a focus on the last four years of research. The studies reviewed highlighted a variety of effective VR applications, particularly beneficial for patients recovering from stroke, cerebral palsy, and spinal cord injuries, among other conditions. These VR interventions demonstrated promising outcomes, including improved motor functions, enhanced community participation, and better psychological and cognitive health, though the definitive impact of VR on rehabilitation outcomes compared to traditional methods is

still under investigation. The review also noted the potential of VR to make neurorehabilitation more engaging, potentially addressing the issue of disengagement common in repetitive traditional therapies. Despite these advances, the application of VR in neurorehabilitation faces significant challenges such as high costs, accessibility issues, and the potential for inducing motion sickness. Further, while VR offers innovative approaches to rehabilitation, its integration with traditional methods could yield more comprehensive benefits. The incorporation of VR into neurorehabilitation represents a blending of technology and healthcare, aimed at enhancing recovery processes and quality of life for those with neurological disorders, though its full potential and implementation require continued evaluation and adaptation.

IV. CHALLENGES OF AI IN NEUROLOGY

Artificial intelligence (AI) in neurology represents a transformative leap forward in medical technology, yet it encounters a series of substantial challenges that must be addressed to ensure its beneficial integration into clinical practice. Data privacy and security are paramount concerns, as neurological data includes sensitive personal and medical information. Ensuring robust cybersecurity measures and adherence to stringent data protection regulations is crucial to maintaining patient trust and preventing potentially devastating data breaches [12]. Additionally, the issue of data integrity and the potential for bias presents a significant obstacle. AI systems are trained on vast datasets, and any inherent biases in these datasets can skew outcomes. This could lead to diagnostic inaccuracies or inequitable healthcare delivery, particularly affecting underrepresented groups [13].

The challenges extend into the operational aspects of healthcare integration. Many healthcare systems rely on outdated infrastructure that is ill-equipped to handle the sophisticated requirements of AI technologies. The cost and complexity of updating these systems can be prohibitive, and the disruption to established procedures can be significant, potentially leading to resistance from healthcare providers. Moreover, there is a pronounced discrepancy between the technological sophistication of AI tools and the current digital literacy of many healthcare professionals. This skills gap means that even if AI tools are available, there may not be sufficient expertise to use them effectively, necessitating comprehensive training programs and ongoing support [14].

The ethical landscape of AI in neurology is also fraught with challenges. The autonomy of AI decision-making processes, often opaque to the end-users, raises serious concerns about accountability and transparency. Patients and practitioners must understand how decisions are made, especially in scenarios involving high-stakes outcomes like neurological disorders. Additionally, ethical dilemmas arise over the consent process for the use of personal medical data in AI training and the potential for AI to make decisions that could conflict with a patient's or family's wishes.

Regulatory issues further complicate the deployment of AI in neurology. The rapid pace of AI development means that technology often outstrips existing legal and regulatory frameworks, which are not always equipped to handle novel issues arising from AI applications, such as data sharing across borders and the use of AI in telemedicine. Policymakers and regulatory bodies must evolve and adapt quickly to create environments that both foster innovation and protect patient welfare.

Ultimately, the integration of AI into neurology, while laden with challenges, also offers unparalleled opportunities for advancements in diagnosis, treatment, and patient care. Overcoming these hurdles will require a collaborative effort among developers, clinicians, ethicists, and regulators to ensure that AI technologies are used responsibly and effectively to enhance the capabilities of neurological medicine.

V. FUTURE PROSPECTS AND EMERGING TRENDS

The landscape of neurology is poised for a paradigm shift driven by advanced Artificial Intelligence (AI) technologies. The imminent future of AI in neurology not only promises enhancements in current applications but also introduces groundbreaking trends that may redefine how neurological disorders are diagnosed, treated, and managed.

One of the most anticipated advancements is the integration of AI with next-generation sequencing and genomics. AI's potential to decipher vast amounts of genetic data can lead to breakthroughs in understanding the genetic underpinnings of neurological disorders. This integration is expected to facilitate the development of precision medicine, allowing for treatments that are tailored to the genetic profile of individual patients. AI-driven genomics could particularly revolutionize the approach to diseases like Alzheimer's and Huntington's, where genetic factors play a significant role [7].

Furthermore, the emergence of neuromorphic computing presents another exciting frontier. Neuromorphic systems are designed to mimic the neural structures of the human brain, offering an exponential increase in processing efficiency and speed. This technology could enable real-time simulations of brain activity, providing insights into complex neural processes and enhancing real-time monitoring and response systems in neurological care [15].

AI is also expected to enhance neuroprosthetics, where the technology's ability to interpret neural signals can be leveraged to improve the control of prosthetic limbs and other assistive devices. Advanced AI algorithms are being developed to more accurately predict and respond to the user's intentions based on neural data, significantly improving the functionality and user experience of neuroprosthetic devices [16].

The prospect of AI-facilitated remote neurology is another trend set to expand. As AI technologies become more sophisticated, remote monitoring and diagnostic capabilities will likely become more prevalent. This could involve the use of AI-driven algorithms to monitor neurological conditions in real-time, using wearable devices that provide continuous data on a patient's neurological health. This capability will be crucial for the management of chronic conditions, potentially reducing hospital visits and allowing for more immediate adjustments to treatment plans.

VI. CONCLUSION

The integration of artificial intelligence (AI) in neurology holds immense promise, with current applications already demonstrating significant benefits in diagnosis, treatment, and management of neurological disorders. AI has shown great potential in enhancing diagnostic accuracy, personalizing treatment approaches, and predicting disease progression. Furthermore, AI-powered technologies such as robotics and virtual reality are revolutionizing neurorehabilitation, offering new avenues for improving patient outcomes.

However, the widespread adoption of AI in neurology also presents significant challenges. Ethical considerations, such as data privacy, algorithm bias, and patient autonomy, must be carefully addressed to ensure the safe and ethical use of AI in healthcare. Regulatory frameworks need to be developed and implemented to govern the use of AI in neurology, ensuring that it meets standards of safety, efficacy, and ethical use.

Despite these challenges, the future of AI in neurology is bright, with emerging trends and developments poised to transform the field. Predictive analytics, integration with other advanced technologies, and advancements in neuroscientific research are just a few examples of the exciting prospects on the horizon. By addressing the challenges and harnessing the potential of AI, healthcare providers can improve diagnosis, treatment, and management of neurological disorders, ultimately improving patient outcomes and quality of life.

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