

Precision Neurology: Redefining Brain Health Through Personalized Medicine

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Opinion

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ABSTRACT

Precision neurology represents a transformative shift in the diagnosis, prevention, and treatment of neurological disorders. Moving beyond traditional symptom-based approaches, it integrates genomics, advanced neuroimaging, biomarkers, and computational analytics to deliver individualized care. This opinion article explores the conceptual framework, clinical applications, technological advancements, and ethical considerations surrounding precision neurology. While the field holds immense promise in improving outcomes for complex neurological conditions such as Alzheimer's disease, Parkinson's disease, and epilepsy, several challenges remain, including data integration, accessibility, and clinical validation. The future of neurology lies in adopting a predictive, preventive, personalized, and participatory model, ultimately reshaping patient care and redefining neurological disease classification.

Keywords

Precision neurology; personalized medicine; neurogenomics; biomarkers; neurodegenerative diseases; artificial intelligence; clinical neurology; genomic medicine; brain imaging; digital health

INTRODUCTION

Neurology has historically relied on clinical observation, patient history, and symptom-based classification systems. However, neurological disorders are inherently heterogeneous, with significant variability in etiology, progression, and treatment response. Precision neurology emerges as a paradigm shift, aiming to tailor medical care based on individual biological, genetic, and environmental factors.

Precision neurology applies the principles of precision medicine to neurological diseases, focusing on individualized care using molecular, genetic, and clinical profiles. This approach recognizes that two patients with the same diagnosis may exhibit entirely different disease trajectories and therapeutic responses, necessitating personalized strategies.

Concept and Evolution of Precision Neurology

The evolution of precision neurology is closely tied to advances in genomics and data science. Traditional neurology emphasized population-based approaches, often derived from randomized controlled trials. In contrast, precision neurology leverages individual-level data, including genomic sequencing, proteomics, and advanced neuroimaging.

Modern technologies now enable "deep phenotyping," where patients are characterized using a combination of genetic, clinical, behavioral, and imaging data. This shift allows clinicians to classify patients into smaller, biologically meaningful subgroups, facilitating targeted interventions.

The foundation of precision neurology lies in the broader concept of precision medicine, which emphasizes prevention and treatment strategies tailored to individual variability. The integration of multi-omic data and computational modeling has further accelerated this transformation.

Core Components of Precision Neurology

1. Genomics and Neurogenetics

Genomics plays a central role in precision neurology. Whole-genome and whole-exome sequencing enable the identification of genetic variants associated with neurological diseases. These techniques allow early diagnosis, risk prediction, and targeted therapy development.

For instance, genetic profiling can identify mutations linked to conditions such as epilepsy or neurodegenerative disorders, enabling personalized treatment strategies.

2. Biomarkers and Molecular Profiling

Biomarkers are critical for disease detection, prognosis, and therapeutic monitoring. These include:

Cerebrospinal fluid biomarkers

Blood-based biomarkers

Imaging biomarkers

The identification of reliable biomarkers remains a key challenge, as many neurological diseases lack well-defined indicators for disease progression.

3. Advanced Neuroimaging

High-resolution imaging techniques, such as MRI and PET scans, provide detailed insights into brain structure and function. These tools facilitate early detection of neurological changes, often before clinical symptoms appear.

4. Artificial Intelligence and Big Data

Artificial intelligence (AI) and machine learning play a pivotal role in analyzing large datasets generated from genomics, imaging, and clinical records. These technologies enable pattern recognition, predictive modeling, and personalized treatment planning.

5. Systems Medicine and Digital Integration

Precision neurology relies on integrating diverse data sources into a cohesive framework. Systems medicine combines clinical, biological, and digital data to create comprehensive patient profiles, supporting informed decision-making.

Clinical Applications

Neurodegenerative Diseases

Precision neurology has significant implications for diseases such as Alzheimer's and Parkinson's. These conditions are characterized by complex pathophysiology and variable progression.

Genomic and biomarker analyses enable early detection and identification of disease subtypes, facilitating targeted interventions. Early-stage identification is particularly crucial, as it offers a window for preventive strategies.

Epilepsy

In epilepsy, genetic testing can identify specific mutations responsible for seizure disorders. This allows clinicians to select targeted therapies, improving treatment outcomes and reducing adverse effects.

Stroke and Cerebrovascular Disorders

Precision approaches can identify individuals at high risk of stroke based on genetic and lifestyle factors. Personalized prevention strategies, including tailored pharmacotherapy, can significantly reduce morbidity and mortality.

Multiple Sclerosis

Precision neurology enables the identification of disease subtypes and prediction of treatment response in multiple sclerosis. This helps clinicians choose the most effective disease-modifying therapies.

Advantages of Precision Neurology

1. Improved Diagnostic Accuracy

By integrating genetic, molecular, and imaging data, precision neurology enhances diagnostic precision, reducing misdiagnosis and diagnostic delays.

2. Personalized Treatment Strategies

Tailored therapies improve treatment efficacy and minimize adverse effects, addressing the limitations of one-size-fits-all approaches.

3. Early Detection and Prevention

Precision neurology emphasizes early detection, enabling preventive interventions before irreversible neurological damage occurs.

4. Better Patient Outcomes

Personalized care leads to improved clinical outcomes, enhanced quality of life, and reduced healthcare costs.

Challenges and Limitations

Despite its promise, precision neurology faces several challenges:

1. Complexity of Neurological Disorders

Neurological diseases involve complex interactions between genetic, environmental, and behavioral factors, making it difficult to develop targeted therapies.

2. Lack of Robust Biomarkers

The absence of validated biomarkers for many neurological conditions limits the effectiveness of precision approaches.

3. Data Integration and Interpretation

The vast amount of data generated from multi-omic and imaging technologies requires advanced computational tools for meaningful interpretation.

4. Ethical and Privacy Concerns

The use of genetic data raises ethical issues related to privacy, consent, and data security.

5. Accessibility and Cost

High costs and limited access to advanced technologies may widen healthcare disparities, particularly in low-resource settings.

Ethical and Social Implications

Precision neurology raises important ethical considerations:

Data Privacy: Protection of genetic and health data is critical.

Equity: Ensuring equitable access to precision medicine technologies is essential.

Informed Consent: Patients must be adequately informed about the use of their data.

Addressing these issues is crucial for the responsible implementation of precision neurology.

Future Directions

The future of precision neurology lies in the integration of emerging technologies and interdisciplinary collaboration. Key trends include:

1. Multi-Omic Integration

Combining genomics, proteomics, metabolomics, and epigenomics will provide a comprehensive understanding of neurological diseases.

2. Digital Health and Wearable Technologies

Wearable devices and mobile health applications enable continuous monitoring of neurological parameters, facilitating real-time interventions.

3. Brain Simulation and Computational Modeling

Advanced computational models may simulate brain function and disease progression, enabling predictive and personalized treatment strategies.

4. Redefinition of Neurological Diseases

Precision neurology may lead to a reclassification of neurological disorders based on molecular and genetic profiles rather than clinical symptoms alone.

Opinion and Critical Perspective

Precision neurology represents a necessary evolution in the field of neuroscience. However, its success depends on balancing technological innovation with clinical applicability. While the integration of genomics and AI offers unprecedented opportunities, it also risks over-reliance on data-driven approaches without sufficient clinical validation.

In my view, the true potential of precision neurology lies not merely in technological advancement but in its ability to bridge the gap between research and clinical practice. The focus should remain on improving patient outcomes rather than pursuing innovation

for its own sake.

Moreover, global collaboration and equitable access must be prioritized to ensure that the benefits of precision neurology are universally realized.

CONCLUSION

Precision neurology is poised to revolutionize the field of neurological sciences by offering personalized, predictive, and preventive care. By integrating genomics, biomarkers, imaging, and computational tools, it addresses the limitations of traditional approaches and enhances patient outcomes.

However, significant challenges remain, including data integration, ethical concerns, and accessibility. Addressing these issues will be critical for the successful implementation of precision neurology in clinical practice.

Ultimately, precision neurology represents not just a technological advancement but a paradigm shift toward patient-centered care, redefining how neurological diseases are understood and treated.

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