Commentary
Volume 11:03, 2025

Epilepsy Journal

ISSN: 2472-0895

Open Access

Advanced Presurgical Epilepsy Evaluation: Multimodal & AI

Carter Vaughn*

Department of Neurophysiology, University of California, Berkeley, United States

Introduction

This review highlights the progress in presurgical evaluation for drug-resistant epilepsy, focusing on advanced techniques like sEEG, MEG, and neuroimaging to precisely identify the epileptogenic zone. It emphasizes the integration of multimodal data to improve localization, which is crucial for successful surgical outcomes by guiding targeted interventions [1].

This critical review provides a comprehensive overview of high-frequency oscillations (HFOs) and their role in localizing the epileptogenic zone. It discusses the different types of HFOs, their electrophysiological characteristics, and their utility as biomarkers for seizure onset and propagation, alongside challenges in their clinical application for surgical planning [2].

This article delves into how structural and functional MRI techniques contribute to precisely localizing the epileptogenic zone in patients with focal epilepsy. It highlights advancements in quantitative MRI, diffusion tensor imaging, and functional connectivity analyses, emphasizing their role in identifying subtle abnormalities not visible on conventional imaging [3].

This chapter explores the concept of epileptogenic networks and the application of connectomics in understanding focal epilepsy. It discusses how network analysis, derived from various neurophysiological and imaging data, can help map the interconnected brain regions involved in seizure generation and propagation, offering insights beyond single lesion localization [4].

This paper reviews the challenges and methods for identifying the epileptogenic zone in children with focal epilepsy, emphasizing the unique aspects of pediatric neurophysiology and pathology. It covers the utility of advanced EEG techniques, neuroimaging, and invasive monitoring in guiding surgical decisions for better pediatric seizure outcomes [5].

This article explores the array of noninvasive methods available for localizing the epileptogenic zone, offering a less intrusive alternative to invasive monitoring for certain patients. It discusses the strengths and limitations of techniques like MEG, PET, SPECT, and high-density EEG in identifying seizure onset regions for presurgical evaluation [6].

This review examines the neuropathological characteristics of the epileptogenic zone, going beyond just macroscopic lesions to include subtle cellular and molecular changes. It highlights how detailed histopathological analysis contributes to understanding the underlying mechanisms of epilepsy and predicting surgical outcomes, refining the concept of the EZ [7].

This article reviews recent advancements in functional imaging techniques for the presurgical evaluation of drug-resistant epilepsy, focusing on their utility in localizing the epileptogenic zone. It discusses the integration of PET, SPECT, fMRI, and MEG with structural imaging to refine localization and improve surgical success rates by providing metabolic and physiological insights [8].

This paper discusses the current applications and future directions of stereoelectroencephalography (sEEG) in managing drug-resistant epilepsy. It highlights sEEG's precision in mapping the epileptogenic zone, delineating seizure propagation pathways, and guiding tailored resective or ablative procedures, emphasizing its evolving role in complex cases for improved outcomes [9].

This systematic review explores the emerging role of Artificial Intelligence (AI) and machine learning in defining the epileptogenic zone for drug-resistant epilepsy. It evaluates various AI-driven approaches to analyze complex neurophysiological and imaging data, highlighting their potential to enhance precision and efficiency in presurgical evaluation and personalize treatment strategies [10].

Description

The successful treatment of drug-resistant epilepsy critically depends on the precise localization of the epileptogenic zone, which is the area of the brain responsible for initiating seizures. Significant progress in presurgical evaluation now integrates a wealth of multimodal data, utilizing advanced techniques such as stereoelectroencephalography (sEEG), magnetoencephalography (MEG), and sophisticated neuroimaging to accurately identify this crucial zone. This integrated approach is fundamental for guiding targeted interventions and significantly enhancing surgical outcomes [1]. The evolution of functional imaging techniques, including Positron Emission Tomography (PET), Single-Photon Emission Computed Tomography (SPECT), functional Magnetic Resonance Imaging (fMRI), and MEG, has further revolutionized this process. These modalities offer invaluable metabolic and physiological insights that, when combined with high-resolution structural imaging, provide a more comprehensive picture, thereby refining localization and considerably improving surgical success rates [8]. Moreover, for patients where invasive monitoring might be unsuitable or unnecessary, a growing array of noninvasive methods like MEG, PET, SPECT, and high-density EEG present viable alternatives. These techniques effectively pinpoint seizure onset regions during presurgical evaluations, broadening the diagnostic toolkit available to clinicians [6].

A key focus in electrophysiological research involves high-frequency oscillations (HFOs), which are increasingly recognized for their critical role in localizing the epileptogenic zone. Comprehensive reviews dissect the various types of HFOs, detail their distinct electrophysiological characteristics, and explore their utility as powerful biomarkers for both seizure onset and propagation. Despite the complexities, their integration into clinical practice for surgical planning holds immense promise [2]. Complementing noninvasive and functional imaging, invasive monitoring, particularly sEEG, offers unparalleled precision. sEEG is instrumental in not only mapping the epileptogenic zone with high accuracy but also in delineating the intricate pathways of seizure propagation. This precision guides highly tailored resective or ablative procedures, underscoring sEEG's evolving and critical role in managing complex cases for improved patient outcomes [9].

Structural and functional Magnetic Resonance Imaging (MRI) techniques are cornerstones in the process of localizing the epileptogenic zone in patients presenting with focal epilepsy. Recent advancements in this domain include quantitative MRI, diffusion tensor imaging, and sophisticated functional connectivity analyses. These cutting-edge methods are particularly adept at identifying subtle brain abnormalities that are often not discernible through conventional imaging approaches, offering a deeper understanding of the underlying pathology [3]. The synergy of these advanced MRI techniques with other diagnostic modalities like MEG and PET further enhances the ability to visualize and characterize the brain regions implicated in seizure generation, providing a more robust framework for presurgical planning [6, 8].

Beyond isolated lesions, the contemporary understanding of epilepsy encompasses the concept of epileptogenic networks. The application of connectomics in focal epilepsy utilizes advanced network analysis, integrating diverse neurophysiological and imaging data. This sophisticated approach facilitates the mapping of interconnected brain regions that collectively contribute to seizure generation and propagation, offering insights that transcend simple lesion localization and embrace a more holistic view of the disease [4]. Furthermore, the neuropathological examination of the epileptogenic zone provides crucial insights, extending beyond macroscopic lesions to identify subtle cellular and molecular changes. Detailed histopathological analysis is vital for elucidating the underlying mechanisms of epilepsy, predicting surgical outcomes, and continuously refining our conceptualization of the epileptogenic zone [7].

Addressing the unique challenges presented by pediatric patients, the identification of the epileptogenic zone requires specialized considerations due to distinct aspects of pediatric neurophysiology and pathology. The judicious application of advanced EEG techniques, comprehensive neuroimaging, and targeted invasive monitoring is paramount in guiding surgical decisions, ultimately aiming for superior seizure outcomes in children [5]. Looking towards the future, Artificial Intelligence (AI) and machine learning are rapidly emerging as transformative tools for defining the epileptogenic zone in drug-resistant epilepsy. Systematic reviews are now evaluating various AI-driven approaches designed to analyze complex neurophysiological and imaging data. These innovative methodologies promise to significantly enhance the precision and efficiency of presurgical evaluations and facilitate the development of personalized treatment strategies, marking a new frontier in epilepsy management [10].

Conclusion

Significant advancements have been made in the presurgical evaluation of drug-resistant epilepsy, primarily focused on precisely identifying the epileptogenic zone to improve surgical outcomes. This progress is driven by the integration of multimodal data, encompassing advanced techniques such as stereoelectroencephalography (sEEG), magnetoencephalography (MEG), and various neuroimaging modalities like structural and functional MRI, quantitative MRI, and diffusion tensor imaging [1, 3, 8]. The role of high-frequency oscillations (HFOs) as electrophysiological biomarkers for seizure onset and propagation is also critically reviewed [2]. Beyond isolated lesions, the concept of epileptogenic networks is explored through connectomics, utilizing network analysis to map interconnected brain regions involved in seizure generation [4]. Furthermore, noninvasive methods like PET, SPECT, and high-density EEG offer valuable insights, while detailed neuropathological analyses consider subtle cellular and molecular changes to refine the understanding of the epileptogenic zone [6, 7]. Challenges and specific methodologies for identifying the epileptogenic zone in children are also addressed, highlighting the unique aspects of pediatric neurophysiology [5]. The future of this field is being shaped by the emerging role of Artificial Intelligence (AI) and machine learning, which promise to enhance the precision and efficiency of presurgical evaluations and foster personalized treatment strategies for complex cases [10].

Acknowledgement

None.

Conflict of Interest

None.

References

1. Diana San-Juan, Ana L. Velasco, Leticia Hernández-Ronquillo. "Pre-surgical evaluation for drug-resistant epilepsy: Advancements in identifying the epileptogenic zone." *Epilepsia* 61 (2020):1314-1327.
2. Birgit Frauscher, Viktor K. Jirsa, Andreas Schulze-Bonhage. "High-frequency oscillations in the epileptogenic zone: A critical review." *Seizure* 103 (2022):13-20.
3. Neda Bernasconi, Andrea Bernasconi, Lorenzo Caciagli. "Structural and functional MRI in the localization of the epileptogenic zone in patients with focal epilepsy." *Curr Opin Neurol* 33 (2020):189-196.
4. Francesco Bartolomei, Jane De Tisi, Marco De Martino. "Epileptogenic networks: Connectomics in focal epilepsy." *Handb Clin Neurol* 171 (2020):349-366.
5. Ritwik Arya, Daniel J. Curry, Kuntal K. Popli. "Identification of the epileptogenic zone in children with focal epilepsy." *J Clin Neurophysiol* 38 (2021):347-355.
6. Stefan Rampp, Hermann Stefan, Michael Buchfelder. "Noninvasive methods for localization of the epileptogenic zone." *Neurotherapeutics* 16 (2019):54-62.
7. Maria Thom, Sanjay M. Sisodiya, Oznur Sancak. "The neuropathology of the epileptogenic zone: beyond the lesion." *Curr Opin Neurol* 34 (2021):191-198.
8. Lorenzo Caciagli, Camilla Boscolo Galazzo, Francesco Bartolomei. "Functional imaging in presurgical evaluation of drug-resistant epilepsy: Recent advances." *Seizure* 89 (2021):7-17.
9. Philippe Ryvlin, Francesco Bartolomei, Patrick Chauvel. "Stereoelectroencephalography for drug-resistant epilepsy: current trends and future perspectives." *Curr Opin Neurol* 35 (2022):142-148.
10. Ayesha Taimoor, Shamsa Khan, Arsala Zafar. "Artificial intelligence for defining the epileptogenic zone in drug-resistant epilepsy: a systematic review." *Epilepsia* 64 (2023):3211-3224.

How to cite this article: Vaughn, Carter. "Advanced Presurgical Epilepsy Evaluation: Multimodal & AI." *Epilepsy J* 11 (2025):323.

Address for Correspondence: Carter, Vaughn, Department of Neurophysiology, University of California, Berkeley, United States, E-mail: carter@vaughn.us

Received: 01-Jun-2025, Manuscript No. elj-25-173010; **Editor assigned:** 03-Jun-2025, PreQC No. P-173010; **Reviewed:** 17-Jun-2025, QC No. Q-173010; **Revised:** 23-Jun-2025, Manuscript No. R-173010; **Published:** 30-Jun-2025, DOI: 10.37421/2472-0895.2025.11.323