AUCTORES
Globalize your Research

Journal of Neuroscience and Neurological Surgery
Aaryan Gupta *

Open Access

Review Article

# Multidisciplinary Perspectives on the Pathophysiology, Treatment, and Management of Epilepsy

**Aaryan Gupta*, Pranav Tandon, Akansha Kumari, Anjali, Bhavya Kaushal, Lovish Jain**

Department of Biotechnology, Sharda School of Engineering & Technology, Sharda University, Greater Noida, Uttar Pradesh, 201310, India

***Corresponding Author:** Aaryan Gupta, Department of Biotechnology, Sharda School of Engineering & Technology, Sharda University, Greater Noida, Uttar Pradesh, 201310, India.

**Received date:** March 18, 2024; **Accepted date:** April 02 , 2024; **Published date:** April 19, 2024

**Citation:** Aaryan Gupta, Pranav Tandon, Akansha Kumari, Anjali and Bhavya Kaushal et.al (2024), Multidisciplinary Perspectives on the Pathophysiology, Treatment, and Management of Epilepsy, *J. Neuroscience and Neurological Surgery*, 15(3); DOI:**10.31579/2578-8868/310**



## Abstract

Recurrent seizures are the hallmark of epilepsy, a complicated neurological illness with a multifaceted aetiology involving cellular, molecular, and genetic factors. Genetic research has made significant strides in identifying the genes and loci linked to epilepsy, which has improved our understanding of the hereditary basis of the condition. Neuronal hyperexcitability is caused by molecular imbalances in neurotransmitter balance and receptor function, whereas cellular dysfunctions, such as anomalies in ion channels, affect the origin of seizures. With the emphasis on individualised treatment, new antiseizure drugs have been made possible by pharmacological developments. For patients who are resistant to medications, neurosurgical procedures such as neurostimulation and corresponding surgery provide options. Neuroimaging methods are vital in the surgical planning process. Potential treatment targets are highlighted by the thalamus's role in the spread of seizures. Patient-centered treatment is crucial since self-management techniques are essential for raising patients' quality of life. This comprehensive overview of epilepsy underscores the necessity of a multidisciplinary approach in research and treatment to improve management and patient outcomes.

**Key Words:** epilepsy, pharmacological treatment, neuroimaging, neurosurgical interventions

## Introduction

Epilepsy is a long-term neurological condition marked by frequent, spontaneous seizures brought on by aberrant, excessive electrical discharges in the brain. These seizures can appear in a variety of ways, from quick spasms or jerks of the muscles to intense, protracted convulsions that may be followed by unconsciousness and loss of control over the bladder or bowel movements [1]. Several factors contribute to the aetiology of epilepsy, including head trauma, brain infections, tumours, developmental abnormalities, and genetic predispositions. A neurological examination, blood tests, and brain imaging methods such as EEG, CT scans, and MRI to measure brain activity and spot possible structural abnormalities are usually part of the diagnosis process [2].

About 50 million individuals worldwide suffer from epilepsy, making it one of the most prevalent neurological conditions. The percentage of people with epilepsy in a population at any particular moment is known as the prevalence of epilepsy, and it varies by location. Nearly 80% of epileptics are thought to live in low- and middle-income nations [3]. An estimated 50.4 to 81.7 new cases of epilepsy per 100,000 individuals annually make up the incidence rate, which shows the number of new cases in a population over a given time period. Numerous factors can impact this rate, such as age—younger and older people tend to have larger incidences—and etiological causes such infections, strokes, and head trauma [4]. The epidemiology of epilepsy is significantly influenced by variations in demographics as well. For example, in the United States, 3.4 million people—3 million adults and 470,000 children—had active epilepsy in 2015, accounting for 1.2% of the population [5].

The pathophysiology of epilepsy is a complex field in which cellular, molecular, and genetic factors interact to cause the disease's characteristic episodes. The DNA mutations that increase the risk of epilepsy have been identified by genetic investigations, which have identified 26 loci, 19 of which are unique to genetic generalised epilepsy (GGE). Furthermore, 29 genes located within these regions probably contribute to the illness [6]. There are differences between focal and generalised forms of epilepsy, and the genetic basis for these conditions is very varied. A disturbance in the balance of neurotransmitters and receptor function, which are essential for neural communication, is a biological hallmark of epilepsy. Neuronal hyperexcitability can result in seizures when there is an excess of excitatory neurotransmitters, such as glutamate, and a deficiency of inhibitory neurotransmitters, such as GABA. Furthermore, there is

evidence linking the risk of generalised epilepsy to proteins that facilitate electrical impulse transmission across neural synapses [7].

Cellularly, a variety of cellular abnormalities can result in aberrant, synchronised neural activity, which is how epilepsy presents. These include alterations in neural connection and network structure, ionic concentration shifts, and ion channel dysfunctions. The pathophysiology of epilepsy is also influenced by inflammatory processes, glial cell function, and the blood-brain barrier's integrity [8]. In the study of epilepsy, the functions of several neurotransmitters and their receptors are closely examined. Neuronal excitability can be altered by mutations in genes encoding ion channels and receptors, which may result in epilepsy. Neuronal network excitability is influenced by changes in synaptic strength, axonal sprouting, dendritic spine modifications, and other structural and functional neuronal changes that accompany the onset of epilepsy [9]. Determining risk factors is essential to comprehending the pathophysiology of epilepsy in its entirety. The start and progression of the condition are influenced by a number of factors, including genetic predisposition, brain damage, infections, and exposure to particular medicines or chemicals. More investigation into these areas opens the door to more focused treatments and better epilepsy management techniques [10].

## Biomarkers for Epilepsy

Finding biomarkers for epilepsy has been a major field of study with the goal of enhancing therapy monitoring, diagnosis, and prognosis. Biological indicators known as biomarkers can show whether a disease is present or how severe it is [11]. These could be biochemical, molecular, or genetic markers of epilepsy.

| Biomarker | Category | Potential Application | References |
|---|---|---|---|
| **S-100B Protein** | Molecular | Indicative of brain cell injury; higher levels found in patients with focal intractable epilepsy. | [12] |
| **EEG Patterns** | Electrophysiological | Diagnostic tool for seizure types and syndromes; can predict seizure recurrence. | [12] |
| **MRI Changes** | Imaging | Identifies structural brain changes associated with epilepsy; aids in surgical planning. | [12] |
| **Genetic Variants** | Genetic | Pinpoints genetic predispositions to epilepsy; assists in personalized treatment. | [13] |
| **Blood Ion Levels** | Biochemical | Monitors changes in blood chemistry that may reflect seizure activity. | [13] |
| **Neuroinflammatory Markers** | Molecular | Indicates inflammation in the brain, which can be involved in epileptogenesis. | [13] |
| **Autoantibodies** | Immunological | Suggests autoimmune epilepsy; guides immunotherapy. | [13] |
| **Cortical Thickness** | Imaging | Assesses brain atrophy related to chronic epilepsy; may guide surgical decisions. | [14] |
| **Metabolomic Profiles** | Biochemical | Reflects metabolic changes in the brain; could predict drug response. | [14] |
| **Brain-Derived Neurotrophic Factor (BDNF)** | Molecular | Associated with neuronal survival and plasticity; altered levels in epilepsy. | [15] |

**Table 1:** Various types of biomarkers used in epilepsy and their potential applications.

## Pharmacological Treatments

Recent years have witnessed tremendous advancements in the field of pharmacological therapies for epilepsy, including the launch of novel agents and the execution of comparative effectiveness studies for second-generation pharmaceuticals. Here's a thorough rundown:

### New Medications:

The arsenal of pharmacological treatments for epilepsy has grown to include more than thirty distinct anti-seizure drugs. Despite this diversity, current treatments fail to provide continuous seizure freedom for one-third of epileptic patients [16]. New pharmaceutical formulations have showed potential, especially for emergency use, and the newest drugs have shown promise as well. These include medications with unique mechanisms of action, such as gabapentin, levetiracetam, lamotrigine, and topiramate [17].

### Comparative Effectiveness Trials:

Comprehending the relative effectiveness of second-generation pharmaceuticals in relation to previous medications and each other is contingent upon these trials. They pay attention to a number of factors, including quality of life, safety, efficacy, and tolerance. For example, a meta-analysis evaluated the safety and effectiveness of newer pharmaceuticals, such as perampanel and lacosamide, as well as broad-spectrum antiseizure medications like lamotrigine, levetiracetam, and topiramate, for the supplementary

treatment of refractory epilepsy. These trials aid in optimising efficacy, reducing side effects, and customising therapy options to meet each patient's needs [18].

### Second-Generation Drugs:

These medications, commonly referred to as newer antiepileptic medicines (AEDs), were introduced after 1985. While they have certain safety benefits over older-generation agents, the percentage of patients who achieve total relief from seizures has not significantly risen. For many of these patients, it is important to evaluate the viability of epilepsy surgery or other therapy as soon as possible [19].

| Drug Name | Type of Seizures | Uses | Efficacy | Limitations | References |
|---|---|---|---|---|---|
| **Carbamazepine** | Focal seizures | Used to control and prevent seizures, especially focal seizures. | High efficacy; first-line treatment | Drug interactions; side effects like dizziness, skin rash | [20] |
| **Valproate** | Generalized and focal seizures | Broad-spectrum use for various seizure types, including myoclonic and absence seizures. | Highly effective; broad-spectrum | Teratogenicity; weight gain; hair loss; liver toxicity | [20] |
| **Lamotrigine** | Generalized and focal seizures | Often used for patients with a broad range of seizure types, including Lennox-Gas taut syndrome. | Good efficacy; well-tolerated | Risk of serious skin rash; requires slow titration | [21] |
| **Levetiracetam** | Broad-spectrum | Suitable for a wide variety of seizure types, often used when other medications are not tolerated. | High efficacy; minimal drug interactions | Behavioral side effects; irritability | [22] |
| **Topiramate** | Generalized and focal seizures | Used for generalized seizures and as a preventive treatment for migraines. | Broad-spectrum efficacy | Cognitive side effects; paresthesia; weight loss | [22] |
| **Gabapentin** | Adjunctive therapy | Primarily used to treat neuropathic pain; has adjunctive use in partial seizures. | Limited efficacy as monotherapy | Generally well-tolerated | [22] |
| **Lacosamide** | Focal seizures | Approved for partial-onset seizures in adults and children. | Effective for focal seizures | Dizziness, headache, diplopia | [23] |
| **Zonisamide** | Focal seizures | Used for the treatment of partial seizures in adults with epilepsy. | Effective for focal seizures | Risk of kidney stones, weight loss | [24] |
| **Phenobarbital** | Generalized seizures | One of the oldest and most widely used antiseizure medications. | Long-standing use for generalized seizures | Sedation, cognitive impairment | [24] |
| **Oxcarbazepine** | Focal seizures | Often used as a first-line treatment for partial seizures. | Similar efficacy to carbamazepine | Hyponatremia, less drug interactions than carbamazepine | [24] |

**Table 2:** Various drugs that have been employed to treat epilepsy.

## Brain Stimulation Techniques

The use of brain stimulation techniques has grown in significance in the therapy of epilepsy that is resistant to treatment. These approaches can be broadly divided into non-invasive and invasive categories, each with unique benefits and drawbacks [25].

| Technique | Uses | Advantages | Limitations | References |
|---|---|---|---|---|
| **TMS (Transcranial Magnetic Stimulation)** | Modulates cortical excitability, used in research for various types of epilepsy | Non-invasive, safe, can reduce seizure frequency | Efficacy varies, more research needed | [26] |
| **DBS (Deep Brain Stimulation)** | Targets deep brain structures like the thalamus to modulate epileptic networks | Can decrease seizure number and severity, long-term benefits | Invasive, does not cure epilepsy, delayed effects | [27] |
| **VNS (Vagus Nerve Stimulation)** | Delivers electrical impulses to the vagus nerve to reduce seizure frequency | Non-invasive, can reduce seizure frequency and intensity | Requires device implantation, may cause voice changes | [28] |
| **RNS (Responsive Neurostimulation)** | Detects abnormal brain activity and delivers stimulation to prevent seizures | Tailored stimulation in response to detected seizures | Invasive, requires device implantation and brain surgery | [28] |
| **Focused Ultrasound** | Uses ultrasound waves to target specific brain areas involved in seizures | Non-invasive, precise targeting | Still experimental, with limited availability | [29] |
| **TNS (Trigeminal Nerve Stimulation)** | Stimulates the trigeminal nerve to potentially reduce seizure frequency | Non-invasive, can be self-administered | Limited data on long-term efficacy | [30] |
| **ANT-DBS (Anterior Nucleus of Thalamus DBS)** | Targets the anterior nucleus of the thalamus to disrupt seizure propagation | Targeted, can improve quality of life | Invasive, potential for side effects | [30] |
| **Cerebellar Stimulation** | Aims to modulate cerebellar output to control seizures | Non-invasive, potential to improve multiple seizure types | Limited evidence, more research required | [31] |
| **Cortical Stimulation** | Applies stimulation directly to the seizure focus in the cortex | Direct targeting of seizure foci | Invasive, risk of brain damage | [31] |
| **Hippocampal Stimulation** | Targets the hippocampus to control seizures originating in the temporal lobe | Can be effective for temporal lobe epilepsy | Invasive, risk of memory impairment | [32] |

**Table 3:** Various brain stimulation techniques that have been used so far.

## Neurosurgical Interventions

When pharmaceutical therapies for drug-resistant epilepsy have failed, neurosurgical operations can let patients hope for a reduction in seizures or even independence from the condition. One of the most popular neurosurgical treatments for epilepsy is called "respective surgery," which entails precisely excising the part of the brain that causes seizures [33]. When seizures are reliably caused by a single, distinguishable brain region that can be safely removed without impairing vital processes, this kind of surgery is most successful. Reconstructive surgery has a variable success rate; between 50 and 90 percent of patients report significant decreases in the frequency of their seizures or achieve seizure-freedom.

As an alternative to traditional reconstructive surgery, laser ablation, commonly referred to as Laser Interstitial Thermal Therapy (LITT), is less invasive. By applying laser technology, LITT is able to precisely target the seizure focus and transfer energy into thermal energy that causes the targeted brain cells to rupture. Patients with seizures arising from tiny, well-defined lesions and those with mesial temporal lobe epilepsy (MTLE) will benefit most from this approach [34]. Because LITT is so precise, the surrounding healthy brain tissue can be preserved, and because it is minimally invasive, patients usually recover more quickly from hospital stays.

A neurostimulator device is implanted inside the skull as part of the innovative therapy known as responsive neurostimulation (RNS). One or two electrodes that are positioned at the seizure focal are attached to this device. The RNS system is designed to continuously monitor brain activity and to provide electrical stimulation in the event that it notices abnormal patterns that may indicate a seizure coming on. By stopping seizures before they begin or limiting their spread, this responsive approach seeks to lower the frequency and severity of seizures. Patients with several seizure foci or a single focus that cannot be safely removed benefit most from the RNS system [35].

Every one of these neurosurgical procedures is customised to the specific needs of the patient, beginning with a comprehensive pre-operative assessment that may involve intracranial electrode monitoring, neuroimaging, and electrophysiological investigations. Accurately locating the seizure focus and weighing the advantages and disadvantages of surgery are the two main objectives. Although these approaches have changed the way that drug-resistant epilepsy is treated, there are still certain hazards involved. Haemorrhages, infections, and neurological impairments are examples of potential consequences. Nevertheless, the possible advantages of lessening or doing away with seizures exceed these hazards for a large number of individuals [36].

## Role of Thalamus in pathophysiology

The thalamus is a key component in the pathophysiology of epilepsy, serving as a focal point that affects the onset and spread of seizures. Its role is most noticeable when it comes to modulating thalamocortical networks, which are essential to the regular operation of the electrical activity in the brain. These networks may become dysregulated in epilepsy, which results in the irregular rhythmic activity that is indicative of seizures.

Seizure Generation: Due to its many connections to the cerebral cortex, the thalamus plays a role in the production of seizures. It contributes to the production of the characteristic 3 Hz spike-and-wave discharges seen on electroencephalograms (EEG) in some forms of generalised seizures, most notably absence seizures [37]. Additionally, the thalamus is linked to focal seizures, where it may enhance and disperse ictal activity across the brain, hence being a major modulator of seizures.

Seizure Propagation: Networks inside the thalamus are crucial for the spread of seizure activity. Sensation data is received by the thalamus, which then transmits it to the cortex. However, in cases of epilepsy, this relay can turn into a channel for the spread of seizures. It is believed that a crucial modulator in this process is the thalamic reticular nucleus, which controls the excitability of thalamocortical neurons. Widespread seizure activity may result from a disruption in the thalamic reticular nucleus' regular inhibitory function [38].

Research Findings: The thalamus's function in epilepsy has been investigated in recent research using a variety of methods, such as deep brain stimulation and intracerebral EEG recordings. Thalamic deep brain stimulation, for example, has been demonstrated to alter seizure clustering and circadian phase locking, as well as seizure risk cycles. Furthermore, stereo-EEG recordings made in the thalamus during assessments for epilepsy surgery have shed light on the roles played by thalamic nuclei in each patient's seizure networks, which has influenced clinical choices about neuromodulation and surgery [39].

Clinical Implications: Comprehending the function of the thalamus in epilepsy bears noteworthy clinical consequences. It provides information for the creation of focused treatments, such as neuromodulation methods meant to upset aberrant thalamocortical rhythms. Clinical investigations such as the SANTE trial4 support the FDA-approved target, the anterior nucleus of the thalamus, for deep brain stimulation in epilepsy. Furthermore, it has been demonstrated that responsive neurostimulation of the thalamus can enhance seizure control in idiopathic generalised epilepsy [40].

The intricate mechanics underpinning this engagement are still being worked out, and this research could lead to the development of new therapeutic approaches. The results of these investigations are essential for expanding our knowledge of epilepsy and enhancing the prognosis of individuals suffering from this difficult neurological ailment.

## Advanced Neuroimaging Techniques

The preoperative evaluation and surgical planning for epilepsy have been completely transformed by advanced neuroimaging techniques, especially in situations of drug-resistant focal epilepsy. These methods aid in the identification of epileptogenic zones and contribute to our understanding of the intricate network that underlies epilepsy [41]. The numerous neuroimaging approaches, together with their benefits, drawbacks, and contributions, are summarised in the table below.

| Technique | Contribution | Advantages | Limitations | References |
|---|---|---|---|---|
| **MRI (Magnetic Resonance Imaging)** | High-resolution structural imaging to identify lesions or anomalies responsible for seizures. | Non-invasive, detailed anatomical information, no radiation exposure | May miss subtle abnormalities, can be expensive | [42] |
| **fMRI (Functional MRI)** | Maps brain activity by detecting changes associated with blood flow, useful in identifying eloquent cortex. | Non-invasive, provides both functional and structural information | Limited temporal resolution, can be affected by patient movement | [42] |
| **PET (Positron Emission Tomography)** | Metabolic imaging to show hypometabolism in the epileptogenic zone4. | Can identify abnormalities not seen on MRI, useful in MRI-negative cases | Involves radiation exposure, less spatial resolution than MRI2 | [43] |
| **SPECT (Single Photon Emission Computed Tomography)** | Captures cerebral blood flow during seizures (ictal SPECT) or between seizures (interictal SPECT). | Can localize seizure focus, especially when MRI is inconclusive | Involves radiation, timing of the scan is critical for accuracy | [44] |
| **DTI (Diffusion Tensor Imaging)** | Visualizes white matter tracts, aiding in understanding connectivity and planning surgical approaches. | Non-invasive, provides insight into white matter integrity | Can be complex to interpret, sensitive to patient movement | [44] |
| **MEG (Magnetoencephalography)** | Detects magnetic fields produced by neuronal activity, localizing seizure onset zones. | High temporal resolution, non-invasive | Expensive, limited availability, requires patient cooperation | [45] |
| **EEG-fMRI** | Combines EEG with fMRI to localize epileptic discharges and related hemodynamic responses5. | Provides both electrophysiological and hemodynamic information | Complex setup, requires simultaneous EEG and MRI compatibility | [45] |
| **ASL (Arterial Spin Labeling)** | MRI technique that measures cerebral blood flow non-invasively. | No contrast agent required, reflects cerebral perfusion | Lower spatial resolution compared to other perfusion methods | [45] |

**Table 4:** Various Neuroimaging techniques that have shown potential in the case of Epilepsy.

**Impact of Epilepsy on Quality of Life**

Patients with epilepsy experience profound effects on their social, psychological, and physical well-being. Beyond the seizures themselves, the chronic nature of epilepsy can cause problems such as cognitive impairments, mental comorbidities, stigma, and a decrease in social support. A reduced standard of living can result from these variables, which can also increase disability days, lower annual incomes, and physical constraints on everyday activities. For people with epilepsy, self-management techniques are essential because they enable patients to actively manage their disease [46]. Understanding the illness, identifying and avoiding seizure triggers, following treatment plans, and leading a healthy lifestyle are all important components of effective self-management. It also entails learning how to control the psychological aspects of epilepsy, like stress management and creating a network of allies.

Case studies demonstrate the advantages of self-management therapies, which have been demonstrated to enhance the quality of life and health outcomes for epileptics. For instance, the Managing Epilepsy Well (MEW) Network supports programmes that provide psychosocial therapy and structured educational initiatives. Clinical investigations have shown that methods such as progressive muscle relaxation, mindfulness-based therapy, and structured physical activity can reduce the frequency of seizures [47]. Furthermore, controlling epilepsy on one's own is not what is meant by self-management; rather, it calls for collaboration between the patient, their support system, and medical professionals. The utilisation of a collaborative approach guarantees that patients receive tailored and optimal care. Healthcare providers are essential in promoting self-care because they offer knowledge, tools, and motivation to practise self-management [48].

## Conclusions

Recurrent seizures are the hallmark of epilepsy, a complicated neurological illness caused by a complex interaction of cellular, molecular, and genetic components. Genetic research progress has led to the identification of particular loci and genes linked to various forms of epilepsy, improving our understanding of its inherited components. Ion channel dysfunctions and changes in neuronal connections are linked to seizure genesis at the cellular level, whereas the dysregulation of neurotransmitters and receptors, such as glutamate and GABA, plays a role in neuronal hyperexcitability. New antiseizure drugs and comparative effectiveness studies have been brought about by advances in pharmacological treatments, which have increased therapy alternatives and highlighted the necessity for individualised treatment plans. In drug-resistant instances, neurosurgical procedures such as responsive neurostimulation, laser ablation, and resective surgery provide promise for seizure reduction, highlighting the significance of accurate surgical planning made possible by cutting-edge neuroimaging techniques.

There has been much attention paid to the thalamus's function in the genesis and spread of seizures, particularly through thalamocortical networks, and studies have suggested that this region may be a promising target for treatment. Considering self-management techniques and quality of life is crucial because epilepsy has a significant influence on patients' lives. Patients' empowerment and health outcomes can be enhanced by effective self-management with the assistance of healthcare professionals. The field of epilepsy research has made significant strides in improving the quality of life and management of individuals with epilepsy through innovative treatment modalities and genetic discoveries. In order to effectively treat the intricacies of this neurological illness, multidisciplinary techniques such as patient-centered care, innovative

pharmaceutical treatments, and state-of-the-art neuroimaging must be integrated. With continued research, epilepsy's complexities may be revealed, opening the door to novel approaches to diagnosis, treatment, and general care.

## References


1. Perucca, E. (2021). The pharmacological treatment of epilepsy: recent advances and future perspectives. Acta Epileptologica, 3(1).
2. Longo, D. L. (2012). 369 Seizures and Epilepsy. Harrison's principles of internal medicine (18th ed.). McGraw-Hill, 3258.
3. Hauser, W. A., & Hesdorffer, D. C. (2019). Epidemiology of epilepsy. Neuroepidemiology, 97-120.
4. Singh, A., & Trevick, S. (2016). The epidemiology of global epilepsy. Neurologic clinics, 34(4), 837-847.
5. Falco-Walter, J. (2020, December). Epilepsy—definition, classification, pathophysiology, and epidemiology. In Seminars in neurology (Vol. 40, No. 06, pp. 617-623). Thieme Medical Publishers, Inc..
6. De Araújo Boleti, A. P., De Oliveira Cardoso, P. H., Frihling, B. E. F., De Moraes, L. F. R. N., Nunes, E. a. C., Mukoyama, L. T. H., Nunes, E. a. C., Carvalho, C. M. E., Macedo, M. L. R., & Migliolo, L. (2024). Pathophysiology to risk factor and therapeutics to treatment strategies on epilepsy. Brain Sciences, 14(1), 71.
7. RCSI. (2023, August 31). Largest genetic study of epilepsy to date provides new insights on why epilepsy develops and potential treatments. ScienceDaily. Retrieved March 17, 2024 from www.sciencedaily.com/releases/2023/08/230831142832.htm
8. Ghosh, S., Sinha, J. K., Khan, T., Devaraju, K. S., Singh, P., Vaibhav, K., & Gaur, P. (2021). Pharmacological and therapeutic approaches in the treatment of epilepsy. Biomedicines, 9(5), 470.
9. Ma, H., & Lin, H. (2021). Advances Regarding neuroinflammation biomarkers with noninvasive techniques in epilepsy. Behavioural neurology, 2021.
10. Kobylarek, D., Iwanowski, P., Lewandowska, Z., Limphaibool, N., & Labrzycka, A. (2019). Advances in the potential biomarkers of epilepsy. Frontiers in neurology, 10, 450539.
11. Simonato, M., Agoston, D. V., Brooks-Kayal, A. R., Dulla, C. G., Fureman, B. E., Henshall, D. C., Pitkänen, A., Theodore, W. H., Twyman, R. E., Kobeissy, F., Wang, K., Whittemore, V., & Wilcox, K. S. (2021). Identification of clinically relevant biomarkers of epileptogenesis — a strategic roadmap. Nature Reviews Neurology, 17(4), 231–242.
12. Pitkänen, A., Löscher, W., Vezzani, A., Becker, A., Simonato, M., Łukasiuk, K., Gröhn, O., Bankstahl, J. P., Friedman, A., Aronica, E., Gorter, J. A., Ravizza, T., Sisodiya, S. M., Kokaia, M., & Beck, H. (2016). Advances in the development of biomarkers for epilepsy. The Lancet Neurology, 15(8), 843–856.
13. Lukasiuk, K., & Becker, A. J. (2014). Molecular biomarkers of epileptogenesis. Neurotherapeutics, 11(2), 319-323.
14. Chen, G., Geng, Y., Jin, B., & Aung, T. (2021). Update on the neuroimaging and electroencephalographic biomarkers of epileptogenesis: A literature review. Frontiers in Neurology, 12, 738658.
15. Weber, Y. G., Nies, A. T., Schwab, M., & Lerche, H. (2014). Genetic biomarkers in epilepsy. Neurotherapeutics, 11(2), 324-333.
16. Sueri, C., Gasparini, S., Balestrini, S., Labate, A., Gambardella, A., Russo, E., Leo, A., Casarotto, S., Pittau, F., Trimboli, M., Cianci, V., Ascoli, M., Cavalli, S. M., Ferrigno, G., Aguglia, U., & Ferlazzo, E. (2018). Diagnostic biomarkers of epilepsy. Current Pharmaceutical Biotechnology, 19(6), 440–450.
17. Vezzani, A., Pascente, R., & Ravizza, T. (2017). Biomarkers of epileptogenesis: the focus on glia and cognitive dysfunctions. Neurochemical research, 42, 2089-2098.
18. He, L. Y., Zhao, R., Fan, L. H., & Wu, C. J. (2021). Natural medicines for the treatment of epilepsy: bioactive components, pharmacology and mechanism. Frontiers in pharmacology, 12, 604040.
19. Wang, H., Wang, H., Liu, Y., Zhao, J., Niu, X., Zhu, L., Ma, X., Zong, Y., Huang, Y., Zhang, W., & Han, Y. (2023). Efficacy and Safety of five Broad-Spectrum antiseizure medications for adjunctive treatment of refractory epilepsy: a systematic review and network meta-analysis. CNS Drugs, 37(10), 883–913.
20. Roustaei, B., Zarezadeh, S., & Ghotbi-Ravandi, A. A. (2023). A review on epilepsy, current treatments, and potential of medicinal plants as an alternative treatment. Neurological Sciences, 44(12), 4291-4306.
21. Riva, A., Golda, A., Balagura, G., Amadori, E., Vari, M. S., Piccolo, G., Iacomino, M., Lattanzi, S., Salpietro, V., Minetti, C., & Striano, P. (2021). New trends and most promising therapeutic strategies for epilepsy treatment. Frontiers in Neurology, 12.
22. Perucca, E., Brodie, M. J., Kwan, P., & Tomson, T. (2020). 30 years of second-generation antiseizure medications: impact and future perspectives. The Lancet Neurology, 19(6), 544-556.
23. Zhuo, C., Jiang, R., Li, G., Shao, M., Chen, C., Chen, G., Tian, H., Li, J., Xue, R., & Jiang, D. (2017). Efficacy and tolerability of second and third generation anti-epileptic drugs in refractory epilepsy: A Network Meta-Analysis. Scientific Reports, 7(1).
24. Perucca, E. (2021b). The pharmacological treatment of epilepsy: recent advances and future perspectives. Acta Epileptologica, 3(1).
25. Dalic, L. J., & Cook, M. (2016). Managing drug-resistant epilepsy: challenges and solutions. Neuropsychiatric Disease and Treatment, Volume 12, 2605-2616.
26. Perucca, E., Brodie, M. J., Kwan, P., & Tomson, T. (2020). 30 years of second-generation antiseizure medications: impact and future perspectives. The Lancet Neurology, 19(6), 544-556.
27. Zaccara, G., & Perucca, E. (2014). Interactions between antiepileptic drugs, and between antiepileptic drugs and other drugs. Epileptic Disorders, 16(4), 409-431.
28. Marson, A. G., Al-Kharusi, A. M., Alwaidh, M., Appleton, R., Baker, G. A., Chadwick, D., Cramp, C., Cockerell, O. C., Cooper, P., Doughty, J., Eaton, B., Gamble, C., Goulding, P., Howell, S., Hughes, A., Jackson, M., Jacoby, A., Kellett, M., Lawson, G. R., . . . Williamson, P. (2007). The SANAD study of effectiveness of carbamazepine, gabapentin, lamotrigine, oxcarbazepine, or topiramate for treatment of partial epilepsy: an unblinded randomised controlled trial. The Lancet, 369(9566), 1000-1015.

29. Somaa, F. A., de Graaf, T. A., & Sack, A. T. (2022). Transcranial magnetic stimulation in the treatment of neurological diseases. Frontiers in neurology, 13, 793253.
30. Zangiabadi, N., Ladino, L. D., Sina, F., Orozco-Hernández, J. P., Carter, A., & Téllez-Zenteno, J. F. (2019). Deep Brain Stimulation and Drug-Resistant Epilepsy: A Review of the literature. Frontiers in Neurology, 10.
31. Abouelleil, M., Deshpande, N., & Ali, R. (2022). Emerging trends in neuromodulation for treatment of drug-resistant epilepsy. Frontiers in Pain Research, 3, 839463.
32. Van Der Vlis, T. a. M. B., Schijns, O., Schaper, F., Hoogland, G., Kubben, P., Wagner, L., Rouhl, R. P., Temel, Y., & Ackermans, L. (2018). Deep brain stimulation of the anterior nucleus of the thalamus for drug-resistant epilepsy. Neurosurgical Review, 42(2), 287–296.
33. Abouelleil, M., Deshpande, N., & Ali, R. (2022). Emerging trends in neuromodulation for treatment of drug-resistant epilepsy. Frontiers in Pain Research, 3, 839463.
34. Bullinger, K. L., Alwaki, A., & Gross, R. E. (2022). Surgical treatment of drug-resistant generalized epilepsy. Current Neurology and Neuroscience Reports, 22(8), 459-465.
35. Fisher, R. S., Acevedo, C. A., Arzimanoglou, A., Bogacz, A., Cross, J. H., Elger, C. E., Engel, J., Forsgren, L., French, J. A., Glynn, M., Hesdorffer, D. C., Lee, B. I., Mathern, G. W., Moshé, S. L., Perucca, E., Scheffer, I. E., Tomson, T., Watanabe, M., & Wiebe, S. (2014). ILAE Official Report: A practical clinical definition of epilepsy. Epilepsia, 55(4), 475–482.
36. Berg, A. T., Berkovic, S. F., Brodie, M. J., Buchhalter, J., Cross, J. H., Van Emde Boas, W., Engel, J., French, J. A., Glauser, T. A., Mathern, G. W., Moshé, S. L., Nordli, D. R., Plouin, P., & Scheffer, I. E. (2010). Revised terminology and concepts for organization of seizures and epilepsies: Report of the ILAE Commission on Classification and Terminology, 2005–2009. Epilepsia, 51(4), 676–685.
37. Evangelista, E., Bénar, C., Bonini, F., Carron, R., Colombet, B., Régis, J., & Bartoloméi, F. (2015). Does the Thalamo-Cortical synchrony play a role in seizure termination? Frontiers in Neurology, 6.
38. Li, Y., Li, J., Lü, Q., Gong, H., Liang, P., & Zhang, P. (2014). Involvement of thalamus in initiation of epileptic seizures induced by pilocarpine in mice. Neural Plasticity, 2014, 1–15.
39. Gregg, N. M., Sladky, V., Nejedlý, P., Mívalt, F., Kim, I., Balzekas, I., Sturges, B. K., Crowe, C. M., Patterson, E. E., Van Gompel, J. J., Lundstrom, B. N., Leyde, K., Denison, T., Brinkmann, B. H., Kremen, V., & Worrell, G. A. (2021). Thalamic deep brain stimulation modulates cycles of seizure risk in epilepsy. Scientific Reports, 11(1).
40. Tung, H., Pan, S., Lan, T., Lin, Y., & Peng, S. (2022). Characterization of Hippocampal-Thalamic-Cortical morphometric reorganization in temporal lobe epilepsy. Frontiers in Neurology, 12.
41. Cendes, F., Theodore, W. H., Brinkmann, B. H., Sulc, V., & Cascino, G. D. (2016). Neuroimaging of epilepsy. Handbook of clinical neurology, 136, 985-1014.
42. Yoganathan, K., Malek, N., Torzillo, E., Paranathala, M. P., & Greene, J. P. (2023). Neurological update: structural and functional imaging in epilepsy surgery. Journal of Neurology, 270(5), 2798–2808.
43. Al-Gahtany, M., Abdrabou, A. M., Elhaddad, A., & Alghamdi, A. (2021). Advances in brain imaging techniques for patients with intractable epilepsy. Frontiers in Neuroscience, 15.
44. Goodman, A. M., & Szaflarski, J. P. (2021). Recent advances in neuroimaging of epilepsy. Neurotherapeutics, 18(2), 811–826.
45. Goodman, A. M., & Szaflarski, J. P. (2021). Recent advances in neuroimaging of epilepsy. Neurotherapeutics, 18(2), 811-826.
46. Rostad, S. E., & Ghearing, G. R. (2022). Self-care and Epilepsy. Current treatment options in neurology, 24(12), 641-654.
47. Bishop, M., & Allen, C. A. (2003). The impact of epilepsy on quality of life: a qualitative analysis. Epilepsy & Behavior, 4(3), 226-233.
48. Strzelczyk, A., Aledo-Serrano, A., Coppola, A., Didelot, A., Bates, E., Sainz-Fuertes, R., & Lawthom, C. (2023). The impact of epilepsy on quality of life: Findings from a European survey. Epilepsy & Behavior, 142, 109179.

**DOI:** 10.31579/2578-8868/312