



ELECTROENCEPHALOGRAPHY IN THE DIAGNOSIS AND MANAGEMENT OF EPILEPSY: A COMPREHENSIVE REVIEW WITH FOCUS ON INDIAN CLINICAL CONTEXTS

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ABSTRACT

Background: Epilepsy remains a major public health concern in India, affecting an estimated 10 million people. Electroencephalography (EEG) is a critical diagnostic and management tool for epilepsy, especially in resource-variable settings like India. It provides real-time brain activity monitoring, aiding in early diagnosis, seizure classification, treatment monitoring, and surgical decision-making.

Objective: This review explores the evolving role of EEG in epilepsy care with a focused lens on Indian clinical contexts, including recent technological advances, region-specific case reports, and health system challenges.

Methods: A systematic review of literature from 2018 to 2025 was conducted using peer-reviewed databases such as PubMed and NCBI. Selected studies included clinical trials, case reports, technological assessments, and regional data on EEG applications in epilepsy.

Results: EEG remains indispensable in epilepsy diagnosis, guiding both pharmacological and surgical management. Video EEG and stereo-EEG support localization in drug-resistant cases. Wearable EEG and AI-powered interpretation systems are improving access and diagnostic accuracy, particularly in underserved Indian regions. Indian studies demonstrate the effectiveness of EEG in identifying rare syndromes like eating epilepsy and in neonatal seizure monitoring.

Conclusion: EEG is a cornerstone in epilepsy care across diagnostic, therapeutic, and prognostic domains. Its evolving technology and integration into clinical practice—especially in the Indian context—underscore its importance. Addressing regional disparities in EEG availability and interpretation remains crucial for equitable epilepsy care.

Keywords: Electroencephalography, Epilepsy, EEG, Video EEG, India, Diagnosis, Seizure Classification, Artificial Intelligence, Wearable EEG, Drug-Resistant Epilepsy

1. INTRODUCTION

Epilepsy is one of the most prevalent chronic neurological disorders, affecting an estimated 50 million people globally, with India accounting for nearly 10–12 million cases—making it the country with the highest burden of epilepsy after China[1]. Electroencephalography (EEG), a non-invasive and cost-effective tool that measures electrical activity in the brain, has remained the cornerstone of epilepsy diagnosis and management since its clinical introduction in the 1930s. Despite the increasing availability of neuroimaging techniques like MRI and PET, EEG continues to be essential in identifying epileptiform activity, classifying seizure types, and guiding therapeutic decisions[2].

In the Indian healthcare context—particularly in resource-limited and rural areas of Central and North-East India—EEG often serves as the primary and sometimes the only neurodiagnostic modality available for epilepsy care[3]. It is especially valuable where access to advanced imaging is restricted, both due to economic limitations and logistical challenges. Several studies from Indian tertiary centers have demonstrated that early EEG assessment significantly improves diagnostic accuracy and treatment outcomes, especially in pediatric and drug-resistant epilepsy cases[4].

Moreover, with the emergence of newer technologies like wearable EEG devices and AI-assisted interpretation, there is growing interest in expanding EEG use beyond urban centers to bridge the diagnostic gap in underserved populations. These technologies have already shown promise in pilot trials, with improved seizure detection rates and reduced diagnostic delays[5].

Given the diverse epilepsy profiles, variable healthcare infrastructure, and growing technological innovations in India, it becomes essential to review the current role, challenges, and future directions of EEG in epilepsy care within this unique clinical context. This paper aims to synthesize global and Indian research to provide a comprehensive understanding of EEG's diagnostic and therapeutic role, particularly focusing on studies and experiences from Indian regions such as Central India.

2. Understanding EEG in Epilepsy

Electroencephalography (EEG) is the primary non-invasive method for monitoring brain electrical activity, and it plays a critical role in the diagnosis, classification, and management of epilepsy. By capturing transient neuronal discharges, EEG provides insights that are not available through imaging, especially in differentiating seizure types and detecting subclinical epileptiform activity [6].

2.1 What EEG Measures

EEG records electrical activity of the brain through electrodes placed on the scalp, primarily measuring postsynaptic potentials from pyramidal neurons in the cerebral cortex. In the context of epilepsy, EEG is used to detect:

- **Interictal Epileptiform Discharges (IEDs):** Sharp waves or spikes between seizures that are hallmarks of epileptogenic regions.
- **Ictal Patterns:** Rhythmic discharges or evolving waveforms that represent seizure activity.
- **Background Activity:** General brain function, which can be slowed in encephalopathies or degenerative conditions.
- **Spectral Features:** Frequency-based patterns (delta, theta, alpha, beta) that may be altered in epilepsy.
- **Functional Connectivity:** Synchronization between brain regions—often disrupted in epileptic networks.

Advanced EEG processing can also include phase-locking values, coherence analysis, and machine learning-based pattern recognition, which are increasingly applied in neonatal and drug-resistant epilepsy evaluations [7].

2.2 Types of EEG Used

The clinical utility of EEG is enhanced through different modalities, each suited for specific diagnostic and management goals:

Table 1. Types of EEG Used in Clinical Practice

EEG Type	Duration	Purpose	Common Use Cases
Routine EEG	20–30 minutes	Basic screening for IEDs	Initial epilepsy work-up
Sleep-deprived EEG	30–60 minutes	Enhances yield of epileptiform activity	Generalized epilepsy, cryptogenic seizures
Ambulatory EEG	24–72 hours	Long-term home monitoring	Infrequent or nocturnal seizures
Video EEG Monitoring (vEEG)	24+ hours	Captures clinical + electrical data	Surgical planning, PNES evaluation
Intracranial EEG (iEEG)	Variable	Direct cortical recording	Pre-surgical localization in DRE
High-Density EEG (hdEEG)	64–256 channels	Spatial mapping	Presurgical mapping, research

Routine and sleep EEGs are commonly used in both rural and urban Indian centers, while vEEG and iEEG are more limited to tertiary hospitals due to cost and infrastructure requirements [6].

3. Diagnostic Role of EEG

Electroencephalography (EEG) is the cornerstone in the diagnostic framework of epilepsy. It provides critical information to confirm the diagnosis, differentiate seizure types, and classify epilepsy syndromes. EEG is often the first neurophysiological tool used when epilepsy is suspected, especially after a first unprovoked seizure. Its diagnostic yield is enhanced when conducted within 24–48 hours of the seizure episode and further improved by sleep-deprivation protocols or repeated recordings.

3.1 Initial Diagnosis and Classification

In early-stage evaluation, EEG assists in determining whether an event is epileptic in nature or caused by non-epileptic paroxysmal disorders such as syncope or psychogenic seizures. EEG captures interictal epileptiform discharges (IEDs) such as spikes, sharp waves, or spike-and-wave complexes, which are considered strong biomarkers of epilepsy.

According to a large-scale review by Dimertsev & Pedyash (2025), approximately 40–50% of patients show abnormal EEG findings after the first seizure, and the likelihood increases with sleep or prolonged monitoring [8]. Early EEG findings are particularly valuable in:

- Classifying focal vs. generalized epilepsy
- Predicting recurrence risk
- Guiding initial antiepileptic drug (AED) selection

In generalized epilepsies, bilateral synchronous spike-and-wave discharges suggest absence seizures or juvenile myoclonic epilepsy, while focal abnormalities may indicate structural lesions or cortical dysplasias [8].

In clinical practice, the absence of EEG abnormalities does not rule out epilepsy. Up to 30% of patients may have a normal first EEG, necessitating serial or sleep-deprived EEG to improve sensitivity [9].

3.2 Epilepsy Syndromes

EEG plays a vital role in identifying epilepsy syndromes, which are defined by specific age of onset, seizure types, and electro-clinical patterns. Syndrome identification is crucial for determining prognosis, treatment plans, and avoiding overtreatment.

Some well-established EEG-supported epilepsy syndromes include:

Syndrome	Typical EEG Features	Age Group
Childhood Absence Epilepsy	3 Hz spike-and-wave discharges during hyperventilation	4–10 years

Juvenile Myoclonic Epilepsy	Generalized polyspike-and-wave	Adolescents
Lennox-Gastaut Syndrome	Slow spike-and-wave, <2.5 Hz, multifocal discharges	Early childhood
Benign Rolandic Epilepsy (SeLECTS)	Centrotemporal spikes, activated during sleep	5–12 years
Temporal Lobe Epilepsy (TLE)	Focal temporal spikes, rhythmic theta	Adults/Adolescents

In difficult-to-localize epilepsies or drug-resistant cases, stereo-EEG (sEEG) and video EEG monitoring (vEEG) are essential. Dimertsev & Pedyash (2025) emphasize that 30–40% of epilepsy patients may require invasive diagnostic approaches like stereo-EEG for precise seizure onset localization—particularly before surgical resection or radiofrequency thermocoagulation [8].

4. Role in Treatment and Prognosis

EEG plays an integral role beyond initial diagnosis in epilepsy—it is vital for monitoring disease progression, assessing treatment response, and planning surgical interventions in drug-resistant cases. Longitudinal EEG data help clinicians evaluate treatment efficacy, detect subclinical seizures, and identify candidates for epilepsy surgery. Advances such as high-resolution EEG and intracranial monitoring have further strengthened the role of EEG in precision epilepsy care.

4.1 Surgical Planning

For patients with drug-resistant epilepsy (DRE), defined as failure of two or more appropriate anti-seizure medications, surgical treatment becomes a key therapeutic option. EEG—especially long-term video EEG (vEEG) and stereo-EEG (sEEG)—is critical in localizing the seizure onset zone (SOZ). A large study by Dimertsev & Pedyash (2025) demonstrated that sEEG combined with radiofrequency thermocoagulation resulted in seizure freedom in over 60% of patients with focal epilepsy who previously failed pharmacologic therapy [8]. The EEG data guided not only resection zones but also thermocoagulation targets in deeply seated cortical areas. EEG is also used to map eloquent cortex (language, motor, memory regions) to avoid functional damage during respective surgery. According to the NINDS Epilepsy Research Plan (2024), more than 70% of surgical candidates in the U.S. undergo EEG-guided functional mapping, and similar practices are now expanding into India’s major epilepsy centers. Moreover, the combination of EEG and advanced imaging (e.g., MRI, PET) significantly increases surgical success rates by allowing multimodal confirmation of epileptogenic zones [9].

4.2 Drug Monitoring and Treatment Adjustment

EEG serves as an important tool for monitoring the effects of anti-seizure medications (ASMs), especially in:

- Evaluating whether epileptiform activity persists despite clinical control
- Detecting subclinical seizures in children and neonates
- Helping guide tapering or discontinuation of drugs in remission
- Differentiating medication side effects from ongoing seizure activity

In a 2023 neonatal EEG study, Elwadhi et al. (2025) showed that serial EEGs were essential in assessing treatment response in neonates receiving levetiracetam and phenytoin [11]. More than 50% of EEG-guided treatment adjustments led to seizure resolution in refractory neonatal seizures. In adolescents and adults, EEG helps distinguish true seizure recurrence from medication side effects or psychiatric comorbidities like PNES (psychogenic non-epileptic seizures), preventing unnecessary dose escalation. The NINDS (2024) also emphasizes EEG’s role in assessing cognitive slowing and generalized background changes, which may indicate overtreatment or toxicity from high-dose ASMs [9].

5. Technological Advances in EEG

The field of electroencephalography (EEG) has seen significant innovation in recent years, driven by advances in wearable technologies and artificial intelligence (AI). These developments are reshaping how EEG is applied in clinical, research, and real-world environments, offering new opportunities for continuous monitoring, real-time interpretation, and personalized healthcare.

5.1 Wearable EEG Devices

Wearable EEG systems have evolved beyond bulky laboratory setups to lightweight, wireless, and portable devices. These innovations enhance comfort, increase mobility, and allow for real-time data acquisition outside traditional clinical environments [12,13]. Modern wearable devices, such as the EMOTIV Insight, use dry electrodes, Bluetooth connectivity, and compact form factors to support applications like mental health monitoring, sleep tracking, and neurorehabilitation [14].

Furthermore, the integration of Internet of Things (IoT) platforms has made it possible to transmit EEG data securely to cloud-based systems for remote diagnosis and monitoring [15]. However, challenges remain in balancing signal fidelity, battery life, and user comfort [16].

5.2 Artificial Intelligence in EEG Interpretation

Artificial intelligence has emerged as a transformative tool in EEG analysis. Deep learning algorithms, particularly convolutional neural networks (CNNs), are increasingly used to classify brain states, detect seizures, and analyze cognitive load with high accuracy [17,18]. These models significantly reduce the manual effort required by clinicians and improve diagnostic speed and reliability.

AI-driven EEG systems also support explainable AI (XAI) frameworks, which offer transparency into how predictions are made—crucial in clinical decision-making [19]. Moreover, combining AI with wearable EEG has enabled personalized and adaptive neurotechnological solutions in mental health, including applications in attention-deficit/hyperactivity disorder [20].

Regional Disparities, Challenges, and Clinical Contexts in EEG Interpretation

Interpretation variability among clinicians remains a significant issue in the Indian clinical context due to the lack of standardized training and certification. This has led to considerable heterogeneity in EEG interpretation skills among neurologists, resulting in inconsistencies in diagnosis and treatment planning. The subjective nature of EEG interpretation further contributes to this variability, even among experienced neurophysiologists, especially in settings outside intensive care units where standardized criteria are less commonly applied [21].

Although automated EEG analysis tools have been developed, they are often sensitive to artifacts and can produce false positives or negatives. These limitations reduce their reliability when compared to expert human interpretation, highlighting the need for ongoing refinement [22]. Additionally, a major barrier is the uneven distribution of trained neurologists across India. In some rural regions, there are as few as 0.03 neurologists per 100,000 people, severely restricting access to accurate neurodiagnostic services [23].

The reliance on manual interpretation also introduces inter-rater variability, with different clinicians potentially offering divergent readings of the same EEG under time constraints [21]. This issue is compounded by the shortage of EEG technologists with formal neurophysiological training. Unlike in several high-income countries, EEG technologists in India often lack certification, which can adversely affect the quality and consistency of data acquisition [21].

To address these challenges, there is a critical need for comprehensive training programs for both clinicians and technologists. These programs should focus on standardizing data acquisition protocols and interpretation guidelines, particularly in light of the increasing burden of neurological disorders across the country.

Emerging technologies such as artificial intelligence (AI) and deep learning offer promising solutions. These tools have the potential to enhance consistency, efficiency, and diagnostic accuracy in EEG interpretation. While challenges remain—particularly regarding model interpretability and data

quality—AI-assisted EEG analysis can serve as a powerful adjunct to clinical expertise, helping to mitigate human error and bridge gaps in neurologist availability [24,25,26].

7. Case Reports and Indian Studies

Table 2. Selected Indian Studies on EEG Applications

Study	Region	Key EEG Findings	Impact
Barthakur et al. (2025) [3]	Northeast India	Ictal EEG revealed food-induced discharges confirming eating epilepsy	Enabled accurate diagnosis and management of a rare reflex epilepsy
Gattu & Murthy (2025) [4]	South India	Video EEG captured NCSE episodes missed in clinical exam	Guided effective treatment and highlighted need for ICU EEG
Singh & Singh (2025) [27]	North India	Routine EEG localized epileptiform activity supporting EPC diagnosis	Supported early drug response and localized cortical irritability
Malapati et al. (2025) [28]	Telangana	Serial EEG showed reduction in neonatal seizure discharges post-Everolimus	Helped monitor response to antenatal therapy in neonates
Elwadhi et al. (2025)[11]	Multicenter (India)	Background abnormalities and burst suppression in neonatal seizures	Assisted in drug titration and prognosis in severe neonatal cases
Balashanmugam et al. (2025) [29]	Pediatric units (India)	EEG showed delta brush-like slowing in OTC deficiency	Helped differentiate metabolic cause of encephalopathy
Joseph & Scaria (2025) [30]	Kerala	EEG differentiated PNES from epileptic seizures	Avoided unnecessary AEDs and directed to psychological care
Aziz et al. (2025) [5]	Semi-urban India	Wearable EEG with AI detected subclinical seizures at home	Expanded access to EEG monitoring in remote areas
Garg & Pandey (2025) [1]	National (India)	Progressive periodic complexes in SSPE diagnosis	Enabled timely diagnosis of SSPE using EEG patterns

8. Limitations and Future Directions

Despite significant advancements in EEG technology and clinical applications, several limitations persist, particularly in resource-constrained settings like many regions in India. Key limitations include limited access to high-quality EEG equipment, a shortage of trained personnel, inconsistent interpretation standards, and low penetration of advanced modalities such as video-EEG and long-term monitoring. Additionally, while artificial intelligence and machine learning hold substantial promise for improving diagnostic accuracy and standardization, their current deployment is limited by data quality issues, interpretability challenges, and the need for large, annotated datasets.

In the future, addressing these gaps will require a multifaceted approach. This includes investment in infrastructure, development of national training and certification programs for EEG technologists and clinicians, and integration of standardized interpretation protocols. Further research is needed to validate AI-based tools in diverse Indian populations and real-world settings. Regional tele-EEG hubs could also bridge the expertise gap in remote areas, enabling wider and more equitable access to neurological diagnostics. Moreover, fostering collaboration between engineers, neurologists, and data scientists can accelerate the development of robust, clinically usable EEG tools tailored to India's healthcare landscape.

9. Conclusion

EEG remains a cornerstone in the diagnosis and management of neurological disorders, particularly epilepsy, in both urban and rural Indian contexts. Recent advancements in wearable technologies and AI have the potential to transform EEG from a specialist tool into a broadly accessible, real-time monitoring solution. However, regional disparities, variability in clinical interpretation, and infrastructural limitations continue to hinder its full utility. Addressing these challenges through standardization, training, policy reforms, and technological innovation is essential. By aligning future efforts with both clinical needs and technological potential, India can enhance the quality and reach of neurodiagnostic care, ultimately improving outcomes for millions affected by neurological conditions.

AUTHOR CONTRIBUTIONS

Conceptualization: Richa Khanna; Writing—original draft preparation: Richa Khanna; Literature review and data curation: Richa Khanna; Supervision, review, and editing: Dr. Ashutosh Jain. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

INSTITUTIONAL REVIEW BOARD STATEMENT

Not applicable. This study is a review of previously published literature and did not involve human or animal participants.

INFORMED CONSENT STATEMENT

Not applicable.

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DATA AVAILABILITY STATEMENT

Data sharing is not applicable as no new datasets were generated or analyzed in this study.

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