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Chapter

The Role of Video EEG Monitoring in Epilepsy Diagnosis and Treatment Processes

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Abstract

Electroencephalography (EEG) remains clinically essential for the classification and diagnosis of epilepsy. Video-EEG is a combined, up-to-date record of the EEG and the patient's clinical behavior. It allows clinical signs and symptoms already acquired in the patient's past clinical history to be correlated with final EEG changes. Video-EEG monitoring (VEM) is a critical tool for the differential diagnosis, differentiation, and pre/post-treatment evaluation of epilepsy. It provides a detailed description of clinical symptoms and analysis of associated EEG changes. It is the gold standard for the differential diagnosis of epileptic seizures from paroxysmal events such as organic non-epileptic seizures or psychogenic non-epileptic seizures. Quantification contributes to the classification of seizure types and epilepsy. It provides valuable information for predicting seizure frequency and identifying precursor triggers. It guides treatment processes together with neuroimaging and psychometric evaluations for pre-epilepsy surgery evaluation. This chapter will comprehensively present the application procedure, evaluation, clinical diagnosis, and the role of video-EEG in treatment processes.

Keywords: electroencephalography, video-EEG monitoring, psychogenic non-epileptic seizures, epilepsy surgery, seizure types, epilepsy syndromes

1. Introduction

Neurophysiological knowledge and neuroanatomical and clinical judgment are complementary for accurate diagnosis, determination of long-term prognosis, and appropriate treatment in neurological disorders. Epilepsy is the expression of dysfunction of part or all of the brain, and optimal treatment often requires a syndromic and aetiological assessment. Clinical ictal symptomatology is usually defined by taking a careful and detailed retrospective history. A comprehensive neuroradiological evaluation is performed when necessary. Clinical suspicion or diagnosis usually requires neurophysiological evaluation. This evaluation is usually obtained with a short-term interictal EEG and repeated if necessary. A standard EEG can provide

important information about interictal abnormalities, risk of recurrence, or pharmacological treatment management. Video-EEG is a combined, up-to-date record of the EEG and the patient's clinical semiology. It allows the patient's past clinical history, signs and symptoms to be correlated with the final EEG changes. It is the gold standard for differential diagnosis and classification, and thus, a better definition of seizure type and subsequent treatment decision or follow-up timing is needed. It provides essential information in defining the type of seizure before surgery. Therefore, an accurate semiological description is made with video EEG, the necessity of diagnostic investigations such as invasive recordings, direct epilepsy surgery, or exclusion from surgical treatment is decided, prognosis is predicted, and treatment (invasive, surgical, or medical) strategies are determined.

2. History and usage areas of EEG

The historical foundations of the recording of bioelectric signals date back to the eighteenth century. In particular, Italian and British scientists have conducted experiments since the early nineteenth century and found that biological tissues are excitable and can directly generate electric currents [1]. Toward the end of this century, the first attempts to record electroencephalographic signals from the cerebral cortex began, and the first human EEG was used in 1924 [2, 3]. In the following years, it was used to confirm the effects of anesthesia during surgery or in the diagnosis of brain tumors [4]. With the clinical use of EEG, knowledge of the literature has increased, and critical studies have been carried out, especially on epilepsy patients [5]. In 1937, Gibbs and Lennox described the first pathological changes associated with epilepsy [6, 7]. In 1950, 8 to 16-channel wired recordings and portable systems were produced. Later, technology in this field developed rapidly, and smaller devices were developed, which are essential for neuromonitoring techniques such as ambulatory EEG and video-EEG [8]. EEG recording, in combination with video for seizure monitoring through a camera, dates back 70 years. 1962 a split-screen closed-circuit video-EEG TV system for epilepsy monitoring was developed [9]. With the advancement of digital technology from 1980 onwards, digital EEG recordings based on computer systems have been developed, which can perform standard EEG, video-EEG, long-term monitoring, etc., and have many more advantages for storing, reviewing, and reformatting data offline [10–12]. Although a century has passed since the first human EEG recording, the interest in EEG as a neurophysiological technique in diagnosis and research continues and still maintains its clinical usefulness.

In this development process, EEG has discovered the dynamic functionality of all brain structures over time. Changes in complex brain networks have become objectively recordable. On the other hand, the development of neuroimaging methods in neuroscience has reduced EEG's diagnostic and localization value. However, it still provides valuable information for many neurological diseases. In addition, the fact that it is a simple, non-invasive, reproducible, and inexpensive neurophysiological method makes it indispensable for the clinical evaluation of the functional state of the brain. It combines functional and metabolic neuroimaging techniques to identify pathophysiological brain networks, predict the epileptogenic site better, and thus achieve better treatment results. Currently, various modalities and recording systems such as standard, ambulatory, long-term monitoring, and video-EEG are applied in clinical epileptology.

3. Standard EEG and video-EEG

Video-EEG is a combined, up-to-date record of the EEG and the patient's clinical semiology. It allows the patient's past clinical history, clinical signs and symptoms to be correlated with the final EEG changes [13]. Differential diagnosis (such as non-epileptic paroxysmal or psychogenic symptoms or cardiovascular disorders) is the gold standard for the classification of seizure type (focal or generalized) and thus for better identification and subsequent treatment decision or timing of follow-up [14–20]. Also, interictal pathologies can be detected during sleep and wakefulness with video-EEG, and their frequency and severity can be measured. It provides essential information in defining the type of seizure before surgery. Thus, prognosis is predicted, and treatment strategies are developed. The quality and usefulness of the information obtained from VEM are far superior to routine EEG for definitive diagnosis. In addition, hospitalization allows gradual discontinuation of anti-seizure medication (ASM) to increase seizure frequency. Seizures are recorded almost 10 times more frequently than the rates detected with routine EEG. Another advantage is that it facilitates capturing different seizure types in the same patient. Thus, seizure patterns that cannot be detected with routine EEG in many patients can be detected, and the diagnosis can be changed [1]. With standard EEG, indirect information is obtained through clinically relevant interictal changes. Interictal abnormalities can be detected in only one out of every five patients. This rate may increase by up to one-third as the duration is prolonged [21]. In addition to electrophysiological examination, simultaneous video recording, detecting both ictal and interictal pathologies, and evaluating detected abnormalities with simultaneous clinical data significantly increase the diagnostic yield [22]. To optimize cost and resource utilization or to detect psychogenic non-epileptic seizures, especially in patients who do not accept long-term inpatient treatment, induction may also be performed for less than 24 hours [23, 24]. The International League Against Epilepsy (ILAE) recommends long-term video-EEG to: quantify seizures, classify epilepsy syndrome and seizure type, and assess electroclinical seizure characteristics before epilepsy surgery [25]. The clinical utility of video-EEG varies greatly depending on patient selection [26, 27]. Video monitoring alone may also be helpful but cannot confirm a definitive diagnosis [13, 25].

There are many indications for performing VEM; Identification, differentiation, classification, characterization of ictal events, recording of seizures, clinical and electrical characterization of episodes, differentiation of non-epileptic paroxysmal episodes, correct diagnosis and correct treatment choice, identification of underdiagnosed epileptic seizures, quantification of seizures and correlation with sleep-wake cycle, identification and analysis of interictal EEG abnormalities and ictal patterns, Monitoring of seizures and ictal discharges during status epilepticus and thus evaluation of treatment benefit, pre-surgical evaluation for drug-resistant epilepsies, identification of seizure semiology by determining the chronological onset of symptoms and signs, localization of the epileptogenic region, determination of nearby or distant cortical areas of spread, determination of anatomical localization in relation to polymorphic seizures and EEG findings at seizure onset in these cases. In all these indications, an accurate semiological identification is made with video EEG, the necessity of diagnostic investigations such as invasive recordings, direct epilepsy surgery, or exclusion from surgical treatment is decided, and treatment (invasive, surgical, or medical) strategies are determined.

4. VEM processes

4.1 Prior and admission to the unit

Before admission to the epilepsy monitoring unit, all patients should be given written information about the purpose and procedures of the planned test, and clinical features of epilepsy, such as seizure semiology, generalization occurrence, etc., should be documented at the outpatient visit during a telephone interview or at the latest during admission. Thus, detailed information about seizure frequency, occurrence of seizure clusters, history of status epilepticus, consequences of seizures, psychiatric or somatic comorbidities, and cognitive problems should be collected. A comprehensive medical history, neurological examination, and a brief psychiatric evaluation should be performed during the presentation. A 12-lead ECG should be recorded. Informed consent forms should be signed by the patient, explicitly stating that continuous video recording will be performed to include VEM data in the medical record and for educational use. Specific risks such as injuries, seizure clusters, generalized tonic-clonic seizures, status epilepticus, postictal psychosis, possible intensive care unit admission, and sudden unexpected death in epilepsy (SUDEP) should be explained to the patient if ASM is reduced or discontinued.

4.2 Technical information: Electrodes and camera system

Since long-term scalp VEM will be performed, gold or silver-plated disc electrodes should be used since they will be reused periodically. The hole should be applied with collodion or square gauze, and the cables should be collected with a patch to reduce the artifact [28–32]. EEG recording systems with at least 64 channels should be available, but in cases where it is necessary, such as extratemporal epilepsy with no pathology detected on MRI or more detailed detection of localization in surgical preparation, the number of electrodes can be increased, and high-density EEG or invasive EEG recordings with 10–10 systems or even up to 256 channels may be preferred. Scalp electrode impedance should be measured and stabilized at baseline and periodically during VEM. Beyond routine protocols, various electrodes can be used in addition to standard electrode placements to localize ictal or interictal activations more accurately. For example, sphenoidal electrodes may be preferred to record activity in the mesial or anterior regions of the temporal lobe, and nasoethmoidal, supraoptic, and auditory canal electrodes may be selected to monitor focal discharges. In addition, effective EEG recordings can be made with stereotactically placed depth, subdural strip or grid, epidural peg or foramen ovale electrodes and their combinations. Surface electromyography (EMG) increases the diagnostic value of video-EEG by non-invasively recording electrical activity from muscles [33]. Specified performance settings are recommended for EEG amplifiers; EEG data acquisition should be performed at over three times the high-frequency filter setting. Higher rates, such as 512 Hz, are preferred to avoid aliasing on modern high-resolution computer displays. A resolution of at least 16 bits per sample should be used for digitization. Interchannel crosstalk should be less than 1%. Additional noise in the recording should be less than 1 mV at any frequency of 0.5–100 Hz [34, 35]. The electrodes should be checked daily or when artifacts occur, and the impedance should be reviewed regularly. Electrodes should be refilled with conductive gel as necessary to maintain low impedance. Small amplifiers can be adequately fixed even in young children, reducing electromagnetic and muscle artifacts. Digital EEG systems analyze signals

with sampling frequencies up to twice the maximum analog sampling frequency. The montages should be adjusted to the individual patient and corrected for abnormalities. Simultaneous ECG and polygraphic recordings are recommended, as cardiac arrhythmias or movements can mimic artifacts. In addition, ECG, EOG, EMG, or respiratory selections may be evaluated by the clinical situation.

Modern video-EEG systems digitally record video and EEG signals, allowing interpretation with various montages. Careful adjustment of filters is essential for accurate assessment of electrical activity. Some EEG systems have developed technologies that automatically detect seizures and interictal abnormalities. These systems attempt to distinguish between seizures and interictal activity over time based on various algorithms that analyze EEG changes. However, computer-based recognition programs are imperfect, and these systems may give false negative or false positive results. Automatically recorded EEG components should be reviewed, confirmed, or rejected by technicians or epileptologists [36].

Video recordings are made using closed-circuit television cameras. These cameras can be black and white and recorded in the dark, thanks to night vision. Video recordings are perfectly synchronized with the EEG so that the onset and development of seizures can be followed, and EEG changes can be compared with clinical events. By using appropriate lighting, accurate recording of the patient's entire body is ensured. Offline visualization with the zoom feature makes it possible to scrutinize important body details. It may be helpful to use two cameras: one to cover the patient's whole body and the other to focus on a detailed part depending on the clinical symptomatology. Well-trained nurses are responsible for patient safety and the integrity of the recording. They must also count the number and duration of seizures each day and report them to the physician. Measures should be taken if the frequency, duration or severity of seizures increases. Continuous surveillance allows detailed review of video and EEG changes, whereas offline review can be time-consuming. Attention to audio recording and lights is essential; a spotlight focused on the patient's face can be added, and different types of microphones can be used. The operator should speak in a normal tone to avoid muting the patient and encouraging them to express their subjective feelings, avoiding echoes when the door is opened or the recording volume is high. In addition, using sheets of a color that contrasts with the skin (e.g., green) helps to detect tiny movements more clearly.

4.3 Activation or provocation methods

During EEG recordings, various activation procedures are used to elicit interictal epileptiform abnormalities and clinical events. Techniques such as eye-opening and closing, hyperventilation, and photic stimulation, which have few or no side effects, allow undetected epileptic activities to be revealed [37–39]. Therefore, activation procedures are critical for confirming the diagnosis of epilepsy and for condition assessment [40]. Provocation methods, such as sleep deprivation and, less commonly, exercise or applying specific stimuli in reflex epilepsies, should be customized for each patient. Reduction of ASM is the most frequently used provocation procedure in this context [41].

4.3.1 Hyperventilation or photic stimulation

Hyperventilation (HV) and intermittent photic stimulation (FS) are routinely applied to increase the likelihood of detecting EEG abnormalities, especially in

specific epilepsy syndromes. HV should be applied for at least 3 minutes; most seizures (>85%) are absences and, in some rare cases, myoclonic seizures. It helps differentiate epilepsy syndromes, especially absence [42, 43]. In focal seizures, results are inconsistent [44, 45]. A slightly longer duration (5 minutes) increases the likelihood of interictal abnormalities [38, 46]. Intermittent FS should be performed in a low illumination environment, with the lamp positioned at least 30 cm away from the patient's eyes. Photosensitivity is more common in women and is an age-related condition, most commonly occurring in late childhood and early adolescence. Mid frequencies between 10 and 20 Hz are most likely to trigger generalized tonic-clonic seizures. This phenomenon is rarely observed in focal epilepsies that do not originate from the occipital lobe [47–50].

4.3.2 Sleep deprivation and reflex triggers

Sleep is one of the most important modulators of seizures and interictal epileptiform abnormalities. EEG recordings made with sleep deprivation increase the likelihood of abnormal findings and help diagnostic processes [44, 51–53]. The relationship between sleep and seizures has long been known; about 90% of epilepsies can be triggered during sleep or by waking up [54–58]. Twenty-four-hour sleep deprivation is recognized as a common practice for this, but drug induction of sleep is controversial [59, 60]. Activities such as reading, speaking and writing are specific activation methods in reflex epilepsy. The role of television and electronic games is also an important factor in photosensitive reflex epilepsy [61–63].

4.3.3 Reduction/interruption of anti-seizure medication

Doses of ASM are often reduced, especially during the pre-surgical assessment period, to shorten the duration of prolonged monitoring in a VEM unit to record seizures. While the doses are being reduced, the types and frequency of seizures should be carefully monitored. This monitoring method is essential for creating patient treatment plans before epilepsy surgery [64, 65]. Although there are no specific protocols, in most patients, it is possible to reduce or completely stop one or more medicines [66, 67]. If tapering or discontinuation of ASM is planned, it is usually done within the first 24 hours after admission. There are very few studies evaluating the systematic tapering of ASM during video-EEG. Rapid dose reduction, although generally less reliable, increases short-term seizure clustering without causing severe adverse events, shortens the time to the first seizure, and consequently significantly shortens the length of hospitalization [66]. An average of 4–7 days is sufficient to complete most of the assessment. A more extended follow-up period than this usually does not provide clinically significant benefit. Rarely, more extended recording periods may be required due to seizures' intermittent and periodic nature. The complication rate is very low and is often related to clinical seizure activity. Close monitoring should be performed in case of complete discontinuation of the drug because it increases the risk of generalized tonic-clonic seizures and the need for rescue treatment [68]. Many factors, such as frequency and type of seizures, history of status epilepticus, and seizure groups, are factors that shape medication taper or withdrawal strategies [69]. It is not recommended to perform this procedure before admission to the hospital as it may create a risk of seizures in an unsupervised environment. In patients receiving polytherapy, the choice of medication to be reduced and the level of reduction is made as an individualized process by evaluating

the frequency and severity of seizures and risk/benefit analysis. The method usually used in centers is to reduce the dose by half on the first day, by three-quarters on the second day, and to continue to reduce the dose by stopping one or all of the drugs until the desired number of events is recorded. If a seizure occurs, the medication may be reintroduced in whole or part, or additional treatment may be administered. An individualized protocol for these arrangements should be written on the patient's card. Suppose ASM has been agreed upon before discharge. In that case, it is recommended to be reintroduced at complete or individualized doses at least 24 hours before discharge, considering the type and severity of the seizure and the care and supervision of attendants in the subsequent period [41]. The duration of hospitalization may be extended for the resumption of ASM, or protocols for contacting on-call doctors after discharge are established [70].

4.4 Video-EEG monitor unit staff

The minimum recommended ratio in the unit is one healthcare professional to four patients. If anti-seizure reduction and other provocation methods are used or intracranial investigations are performed, a ratio of two patients to one healthcare professional is recommended to improve patient safety and ensure the effectiveness of monitoring processes [41]. During the monitoring process, careful supervision of patients is essential for accurate reporting, recording, and review of clinical events. Detection of seizures by monitoring staff or the patient with a button or verbal stimulus is important to ensure optimal video and EEG quality throughout the recording. Patients should be trained to report the onset of subjective symptoms immediately. Monitoring staff should be able to assess the types and frequency of seizures and observe cognitive status. During and after ictal events, patient safety should be ensured, subjective sensations should be identified, and neurological function should be carefully monitored. Ictal/posttal semiological features and changes that cannot be observed on video recordings should be reported. For individuals with suspected non-epileptic events, additional tests should be performed, and the patient should be asked whether the event is typical [71–73].

Signed informed consent is obtained before admission, together with a screening investigating epilepsy characteristics and possible comorbidities. Personal clinical data, detailed clinical history, monitoring diary, and EEG recording type should be planned for each patient. Electrode placement should be performed in a private room, and recording quality should be verified daily. Patients should be taught simple rules such as not touching the electrodes, not taking sweets, or chewing gum. Retention of all video-EEG recordings is not recommended; data for significant events should be retained for analysis. Analysis of clinical events should be concluded with an assessment of neurological functions and treatment recommendations. Medical staff in the unit should receive adequate training in clinical seizure semiology and EEG-based seizure recognition. Staff should have the ability to detect significant cardiac rhythm disturbances and should be competent in the management of patients during and after seizures, initiation of therapeutic interventions by predetermined protocols, and cardiopulmonary resuscitation [74].

Protocols for the management of various types of seizures should cover conditions such as generalized tonic-clonic seizures, seizure clusters, status epilepticus, and challenging postictal behavior. These protocols should be customized with written notes in each patient's file. In generalized tonic-clonic seizures, airway, breathing and circulation should be evaluated, aspiration precautions should be taken quickly

if necessary and oxygen therapy should be provided. Staff should remain with the patient until the patient regains consciousness. In addition, patients should be monitored for signs of postictal psychosis.

4.5 Safety precautions

Ensuring the safety of epilepsy patients during follow-up in the unit is of critical importance. Seizures can bring the risk of severe injury and death for patients [75–78]. It has been reported that safety protocols are lacking in most cases, especially bilateral tonic-clonic seizures, status epilepticus, and seizure clusters. Therefore, it is recommended that appropriate safety guidelines for inpatients and outpatients be established through a formal training program [79]. Video monitors and nurse alarms should be used in addition to direct observation to ensure patient safety. Rapid access and protocols for cardiac arrest management are essential. Common complications include status epilepticus, injuries, and postictal psychosis. Although the risk of shoulder dislocation in convulsive patients in the lateral decubitus position is less than 1% (dislocated shoulder occurs in the lower part in all cases), this can lead to disabling complications. The risk of aspiration is higher in the postictal rather than ictal phase of a generalized tonic-clonic seizure; therefore, the lateral decubitus position should only be applied after the cessation of convulsion, when oral secretions are not increasing or respiration has stopped. In individuals with seizures, secretions may be more effectively controlled by bedside aspiration of the oral cavity. Bed guards and anti-suffocation pillows should be used for all these situations, and an environmental protection plan should be made. Thus, quality and safe care delivery will be ensured [70, 80, 81].

4.6 Cardiac and respiratory monitoring

The cardiac arrhythmia rate during VEM recording was 2.75%. Potentially cardiac severe abnormalities such as asystole, bradycardia, atrioventricular conduction block, atrial flutter, atrial fibrillation and even ventricular fibrillation have been reported in the periictal period. Ictal arrhythmias are usually self-limited, whereas postictal arrhythmias have been associated with SUDEP. Muscle artifacts may prevent the detection of ictal arrhythmias with single-lead ECG. However, 3-lead ECG provides better agreement and is more reliable than conventional 12-lead ECG. Oxygen saturation measurement by pulse oximetry provides essential information, especially in patients with epilepsy associated with persistent localization at night. Desaturation below 90% is more common at temporal and right hemispheric seizure onset when seizures spread contralaterally and in the male gender. The degree of desaturation is associated with seizure duration and electrographic evidence of seizure spread to the contralateral hemispheric area. Central apnea/hypopnoea or, more rarely, mixed or obstructive apnea may be seen in seizures [70]. Ictal hypoxemia, hypercapnia, and prolonged desaturation may contribute to SUDEP by not allowing repositioning of the head to allow ventilation associated with postictal immobility. Optimal alarm selection should be made for continuous pulse oximetry monitoring. Generalized tonic-clonic seizures have a two to three times greater SpO_2 threshold drop compared to focal seizures. It seems reasonable to choose a higher threshold (approximately 86%) for those who tend to give fewer false alarms and a lower threshold (approximately 80%) for those who give more false alarms [82].

4.7 Adverse events

The most common events are falls/injuries and related complications (fractures, etc.), status epilepticus, and postictal psychosis. More rarely, ictal psychosis, cardiorespiratory complications, suffocation/aspiration, and death are observed. Since status epilepticus is a common complication, the management of seizure clusters should be done carefully, and patient-specific protocols should be organized. An intravenous cannula, which is regularly flushed, is inserted for emergency drug interventions, especially in patients with an ASM set-up. Protective measures should be implemented to prevent seizure-related injuries, such as reducing bed height, guard rails, padded bed sides, anti-choking pillows, or placing a mattress on the floor (for hypermotor seizures). In the observation room, there should be protection from hard edges, removal of obstacles, soft toilet seats and recessed sinks in bathrooms, and physical protection. Reducing ASM will increase not only seizure frequency but also seizure intensity and duration, which increases the risk of serious injury. These patients should generally remain in bed, be in the camera's field of view, and receive staff assistance when going to the toilet. As SUDEP occurs mainly at night, continuous and close supervision should be in place for rapid seizure management at night. Ideally, a suitably trained staff member should supervise no more than two patients whose ASM is being reduced/cut.

4.8 Assessment of records

All video and EEG data are reviewed daily to analyze recorded and interictal/subictal EEG data, detect missed or subclinical seizures, and obtain information about other clinically essential events. Daily multidisciplinary rounds are performed to improve patient safety and optimize treatment plans, the unit team is briefed, results are shared with patients, and ongoing monitoring is planned. Clinical seizure semiology provides essential data on seizure onset and propagation pathways. However, these data can be obtained by carefully evaluating clinical behaviors during and after seizures and subjecting the patient to some tests [83].

4.8.1 Interictal EEG

VEM provides more comprehensive information about interictal epileptiform discharges due to the longer recording time and the inclusion of slow wave sleep in the recordings. On the other hand, in focal epilepsy, interictal epileptiform discharges may not be seen in one in ten patients, even during prolonged VEM. Anterior temporal spike waves, the typical interictal EEG pattern of mesial temporal lobe epilepsy, can be distinguished unilaterally or bilaterally. Bilateral independent interictal epileptiform discharges indicate the presence of bitemporal epileptic activity. A higher incidence of seizures occurring independently in both temporal lobes offers a prediction of unfavorable postoperative seizure outcomes. Since the electrophysiological activity of the mesial frontal and orbitofrontal cortex is not accessible with scalp electrodes, up to 50% of interictal epileptiform discharges in frontal lobe epilepsy cannot be demonstrated with standard protocols. Usually, there is hemispheric, bifrontal, multiregional, generalized epileptiform activity, or no activity is detected. With additional electrodes on the affected lobe, regional epileptiform activity can be detected in only half of the cases. In parietal and occipital lobe epilepsy, the localization value of interictal scalp EEG is limited. Diffuse, bitemporal or multisite

spikes and secondary bilateral synchronization are frequently seen. Accurate analysis of interictal epileptiform discharges during non-invasive VEM is critical in drug-resistant extratemporal epilepsy without lesions on MRI and should be carefully evaluated. Localized interictal epileptiform discharges on scalp EEG are the strongest predictor for a good surgical outcome in these patients.

4.8.2 Ictal EEG

In focal epilepsy, the localization value of scalp ictal EEG is higher than the lateralization value. False localization or lateralization is very low. For both, the most accurate detection is almost entirely in temporal seizures. Accuracy is halved in extratemporal seizures. Seizures with the least detectable lateralization commonly originate in the mesial frontal lobe. Initial or delayed regional, temporal 5–9 Hz rhythmic discharge is the most common pattern seen in epileptic seizures originating from the mesial temporal lobe. In frontal lobe epilepsy, one-third do not show ictal EEG changes, one-third show non-lateralized slowing, rhythmic activity or repetitive spiking, and the remaining one-third show lateralized or localized ictal EEG patterns. Muscle and movement artifacts usually obscure seizures from the mesial frontal lobe or cingulate gyrus. Seizures originating from the lateral frontal convexity may show localized EEG patterns. In parietal and occipital lobe epilepsy, the localization value of ictal EEG is minimal, as ictal EEG changes usually become visible after spreading to the frontal or temporal lobes. Therefore, they may show a false localization or lateralization or may not be localized at all. The detection rates of false lateralization and false localization are approximately one in four in occipital seizures and approximately one in seven in parietal seizures.

4.8.3 Reporting of the results

It is recommended that the VEM report should include three primary data:

1. *Clinical problem and objective:* Explanation of the clinical problem and the general purpose of the VEM (diagnostic work-up, pre-surgical evaluation, etc.), brief clinical history and summary of physical findings, reasons for referral or hospitalization, and a short review of current medications and other conditions should be provided.

2. *Technical information:* Observations such as type and location of electrodes, number of channels recorded, use of manual and automatic seizure and/or discharge detection, sleep assessment, cardiovascular monitoring, oximetry, testing of reaction times, activation procedures and medication tapering, if applicable, should be noted.

3. *Conclusions and interpretation:* After a clear, comprehensive, and comprehensible statement of EEG and clinical seizure semiology and electrographic and behavioral correlations, general impressions and their clinical significance should be stated.

Nowadays, to improve the quality of VEM evaluation and reporting, create a multinational database, and help neurophysiologists/epileptologists, the results of computer-aided analysis of the definition of clinical semiology have started to be included in the report.

5. Indications, clinical importance, and advantages of VEM

While in the past, the diagnosis of epilepsy was based on a comprehensive history and physical examination, today, VEM plays an essential role in the diagnosis and treatment processes. Its excellent temporal resolution allows online monitoring of neurological functions. Long-term monitoring of the scalp and synchronized video-EEG recordings are practical tools for localization of the epileptogenic zone in identifying surgical candidates. Digital storage and EEG digitization have helped improve information quality and reduce artifacts. The most common reasons for its use include differential diagnosis, pre-surgical evaluation, and identification of seizure types. Thus, the suitability of individuals with drug-resistant epilepsy for surgery, diagnosis, and current treatment methods in cases of psychogenic origin are reviewed. The simultaneous recording of signals from multiple generators such as EEG, ECG, and EMG has documented the relationship between ictal semiology and EEG [84–86]. On the other hand, well-trained interdisciplinary teams are needed to adequately address clinical findings effectively. It is a time-consuming method, and the average cost of the non-invasive diagnostic phase is high [87, 88].

There are five main indications for video-EEG applications. *Differential Diagnosis:* It is used to differentiate epileptic/non-epileptic seizures (including conditions such as psychogenic seizures, sleep disorders, panic attacks, cardiogenic attacks, fainting, and movement disorders). *Quantification, seizure types, and epilepsy classification:* Seizures, interictal, and ictal epileptiform discharges are quantified. Seizure types are defined, and epilepsy is classified by evaluating electrophysiological findings together with the clinical semiology of the seizure. *Estimation of seizure frequency:* How often seizures occur is evaluated. *Determining the precursors causing seizures:* Seizure triggers such as self-induction or reflex epilepsy are identified. *Pre-surgical evaluation:* It is used to determine the localization of the seizure focus and, thus, to select suitable patients for surgical intervention.

VEM is an essential tool in differentiating epileptic and non-epileptic events. Considering that 25% of epilepsy patients are misdiagnosed, the use of high-resolution imaging techniques together with EEG is of great importance in making the correct diagnosis. Suspicion of epilepsy, loss of consciousness, transient mental disorders, dizziness, fear, panic, aggressive behavior, abnormal movements, behavioral disorders, and sleep-related phenomena such as fainting or sleepwalking, incontinence, or crying may be associated with various conditions. Non-epileptic seizures may be of organic or psychogenic origin; psychogenic seizures may occur as a result of panic attacks or reliving traumatic events. Furthermore, psychological factors have the potential to trigger seizures in patients with epilepsy. In most patients, the diagnosis of epilepsy is based on a clear seizure description confirmed by interictal EEG and imaging modalities in waking and sleeping states. In many epileptic seizures, EEG changes occur during the attack. However, this may not be the case in some simple partial and frontal lobe seizures, or EEG changes recorded during epileptic seizures may not always contain epileptiform discharges. In some individuals, uncertainty regarding epileptic or non-epileptic seizures may persist. These conditions can be clarified in most patients when observed during VEM. Since treatment depends on the diagnosis, it is of critical importance. Many centers are used to distinguish between epileptic and non-epileptic seizures.

Psychogenic seizures rarely start during sleep; sleep-induced seizures are usually epileptic in origin. Short and frequent sleep-onset seizures characterize nocturnal frontal lobe epilepsy. These seizures are associated with automatisms that can render the EEG unreadable. In these seizures without identifiable EEG changes, they may be misdiagnosed as non-epileptic seizures unless attention is paid to several semiological information, such as the fact that there is usually an interval of a few seconds between awakening and seizure onset, the movements tend to be regular, brisk and symmetrical, and the movements do not change with the intervention of the observer during the seizure. It is the gold standard for determining whether sleep-induced seizures are epileptic or non-epileptic. On the other hand, it is tough to make a differential diagnosis when both are present (mixt pattern). In this case, care should be taken not to make assumptions about other seizures based on a few recorded seizures.

Few studies have evaluated the diagnostic yield of VEM. It has been found that the diagnosis remains unchanged in approximately one-third of patients who undergo VEM recording for diagnostic clarification. The most commonly used indication with good results is epilepsy-psychogenic non-epileptic seizures (PNES), followed by focal-generalized epilepsy (especially for the differentiation of frontal lobe seizures from generalized seizures and non-epileptic attacks).

5.1 Diagnosis of non-epileptic seizure

Psychogenic non-epileptic seizures (PNES) can be clearly distinguished from epileptic seizures by the presence of prolonged attacks, a fluctuating course, asynchronous movements, pelvic thrusts, asynchronous and unrelated head or body movements, closed eyes during the attack, ictal crying and recall of the process. On the other hand, seizures occurring during sleep and postictal confusion confirmed by EEG are among the essential findings supporting the possibility of epileptic seizures. It is a fundamental principle of medical practice that the final clinical diagnosis should be made meticulously, including all available data, and should not be based on one symptom alone. VEM is considered the gold standard for diagnosing PNES, and the importance of inter-rater agreement as the best measure of diagnostic reliability should not be underestimated. However, even among competent epileptologists, agreement for PNES or physiological non-epileptic episodes remains at lower levels compared to the diagnosis of epilepsy. In this context, evaluating patients with vague paroxysmal events with VEM is important and necessary to improve the accuracy of the diagnostic process.

5.2 Diagnosis of epilepsy syndrome

Clinical seizure semiology provides critical information about the lateralization and localization of the seizure onset site. This semiology includes subjective symptoms experienced by the patient, such as aura, and objectively observable and testable symptoms, such as motor and autonomic symptoms and changes in awareness. This plays a vital role in determining seizures' localization and lateralization characteristics and highlights the importance of systematic ictal and postictal testing. An accurate description of the semiological characteristics of seizures is crucial for the classification of epileptic seizures and syndromes and for the determination of seizure type and lateralization. Therefore, as part of clinical practice, systematic assessment of seizure semiology improves the accuracy of epilepsy diagnosis and contributes to the determination of appropriate treatment approaches. The distinction between focal

and generalized seizures has a decisive influence on medical and surgical treatment strategies. For example, in individuals with a definitive diagnosis of epilepsy based on history and/or previous interictal EEG findings, video monitoring may be required to distinguish between spike and wave activity observed during absence seizures and short complex partial seizures or between focal discharges or diffuse EEG slowing and generalized and secondary generalized tonic-clonic seizures. This distinction is crucial in determining appropriate treatment modalities and identifying conditions requiring surgical intervention. On the other hand, not only differentiating from generalized epilepsy but also the correct identification of focal seizures plays a critical role in determining the patient's response to treatment and the strategy to be followed in the management of seizures. Therefore, meticulous classification of seizures is essential to increase the success rate in medical and surgical treatment processes.

VEM can detect previously unrecognized or rare seizures, especially when ictal symptoms are mild or consist of normal behaviors such as blinking, head movements, or smiling. Such non-specific events, under-reporting of symptoms by the patient (neonates and young children), or poor performance at school (due to seizures) can lead to diagnostic delay or diagnostic confusion. Seizures involving negative symptoms such as aphasia and motor slowing will not be detected during VEM unless the patient is interacting with others. The epileptic nature of mild seizures can only be determined by establishing a consistent relationship with EEG changes. In this context, video-EEG monitoring allows precise observation of the ictal semiology of seizures while allowing a detailed examination of interictal EEG findings. Seizure recording is important in evaluating non-specific events, especially in children and neonates.

5.3 Prediction of seizure frequency

It is an effective method for estimating seizure frequency, especially in cases with frequent seizures such as absence epilepsy, and this estimation plays a critical role in adjusting drug dosage and administration regimens. In a small proportion of patients, estimation of seizure frequency may also be necessary to evaluate the efficacy of surgical treatment.

5.4 Identification of precipitating factors

Inadequate treatment response may be due to external factors that precipitate seizures. These factors may be specific, such as visual patterns, reading, and eating, as in reflex epilepsies, or general, such as sleep deprivation, stress, alcohol consumption, or menstruation. Some patients learn the trigger factors. Identifying these potential triggers can be necessary for the treatment process for those who do not recognize them. However, in reflex epilepsies (especially photosensitive epilepsy), identifying self-induced seizures can be a challenge, as patients may avoid talking about their habits. Observation of maneuvers may not be sufficient to distinguish between an ictal event or a triggering factor. Manipulations such as removing the root cause of the trigger (e.g., darkening the room) or changing its direction may be used to reach a conclusion.

5.5 Epileptic focus localization and preoperative evaluation

Individuals suffering from drug-resistant epilepsy may become a suitable candidate for surgical resection treatment when a single focus is identified as the source

of seizures. Video monitoring is critical in the diagnostic process to determine the presence and location of these foci. While recording seizures is essential to the diagnostic process, detailed examination of interictal abnormalities can also contribute significantly to the diagnostic evaluation. In focal seizures, the changes observed on scalp EEG at the onset of the seizure are usually lateralized but more often bilaterally distributed and begin after the onset of clinical symptoms. Intracranial electrodes may be required to determine the focal point in a relatively small proportion of patients. Only a limited proportion of patients evaluated for surgical intervention have non-epileptic episodes; in such cases, VEM is essential to definitively confirm the diagnosis of epilepsy. In this context, VEM plays a vital role in accurately classifying and evaluating seizures and treatment planning and contributes to the development of clinical practice.

The main objectives of VEM in preoperative epilepsy evaluation are documentation of clinical seizure semiology, detection of non-specific abnormalities and epileptiform discharges in all phases of the sleep-wake cycle, interpretation of ictal EEG changes, and their relationship with clinical seizure semiology. This comprehensive evaluation facilitates the characterization of seizures and the determination of treatment strategies.

5.6 Development of and current studies

A working group established by the International League Against Epilepsy (ILAE) and the European Epilepsy Monitoring Unit Association has developed a comprehensive standardized seizure test set consisting of 10 items with clinically relevant semiological features designed to adapt to the dynamics of individual seizures. Studies have prospectively demonstrated the applicability of this set in 93% of seizures. The only difficulty encountered during the implementation process was in very short seizures. These findings suggest that the test may be essential in diagnosing and treating epilepsy [71].

A new method called the "Automatic Response Test in Epilepsy" (ARTiE) has been developed to evaluate behavioral responses during seizures in epilepsy patients. Behavioral tests with questions or commands can be performed in the ictal phase in 50% of seizures, in the postical phase in 73%, and in both phases in 80%. The ARTiE method involves recorded video behavioral tasks automatically triggered in the patient's room by computerized seizure detection. ARTiE stands out by offering an automated and standardized method that allows the assessment of behavioral responses at different stages of seizures through video recordings in patients' natural environments. Hopefully, this method will be successful in providing comprehensive and reliable behavioral assessment during seizures. It is considered a new tool that can be used in epilepsy research and clinical applications [72].

The high cost, long hospital waiting times, and other disadvantages of in-hospital VEM burden the patient and family. With the rise of telehealth, home video-EEG monitoring (HVEM) using portable EEG equipment and video cameras has recently come to the fore. In studies, HVEM seems to be a cost-effective and promising option, especially in patients with minimal seizure frequency of approximately one seizure per week, more prominent for children with special needs [79, 89].

Another issue is that wearable technologies will fulfill some of the information obtained from VEM. Although it does not provide additional information about

semiology and electrophysiology, it may be useful for out-of-hospital follow-up of specific patient groups. In a recent study, the performance of a particular application developed for tonic-clonic seizure monitoring was evaluated on a wearable consumer device, and it was reported that seizure monitoring was feasible in daily use; the results were more accurate and provided a lower false alarm rate than an epilepsy monitoring unit [90]. Although not suitable for stand-alone use, it may be available to clinicians shortly as part of the process related to the follow-up processes of patients evaluated in VEM.

Artificial intelligence-based studies have also become interested in this field. A study examining the value of a machine learning approach in predicting epilepsy surgery outcomes using artificial neural network modeling of EEG offers higher accuracy in seizure outcome prediction [91].

6. Conclusion

Detailed descriptions of the clinical manifestations of seizures and analysis of associated EEG changes are critical for the diagnosis and differentiation of epilepsy. Indications include differential diagnosis of epileptic seizures, paroxysmal events (including non-epileptic organic or psychogenic seizures); characterization of seizure types and classification of electroclinical syndromes, measurement of seizures, interictal and ictal epileptiform discharges and pre-surgical evaluation in patients with medically refractory epilepsy.

VEM standards representing minimum requirements have been established, but some variability in individual practice will remain due to local conditions and special patient groups. Prior to admission to the unit, patients should be informed of the purpose and procedures and signed informed consent, and standardized questionnaires and examinations should be used to determine clinical characteristics. Taper/withdrawal of antiepileptic drugs should be individualized for each patient. Records should be made according to established guidelines and cardiorespiratory monitoring should be included. Maximum attention should be paid to patient safety and indicators for reporting quality and safety should be developed. VEM standards should be developed with standardized ictal testing protocols and computer-based organized reporting to facilitate data exchange and collaboration between units.

Digital EEG and computer-assisted technologies significantly increase the possibility of capturing multiple ictal episodes by allowing long-term recording. In particular, observing seizures occurring during nocturnal sleep or at the time of awakening helps to identify interictal abnormalities that become apparent during sleep. For the accurate evaluation of such conditions, 24-hour recordings provide a great advantage. Recording EEG signals and other polygraphic parameters such as peak heart rate, muscle activity, respiration, or eye movements increases diagnostic accuracy. Video-EEG also provides essential information in the differentiation of psychogenic non-epileptic seizures. It contributes to the prevention of misdiagnosis, thus avoiding prolonged exposure to anti-seizure drugs and their side effects and stigmatization that may confirm psychosocial problems.

In conclusion, the application continues to be developed and used more effectively for diagnostic differentiation of epilepsy, seizure type and syndrome detection, and evaluation before epilepsy surgery.

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Conflict of interest

The authors declare no conflict of interest.

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