Epileptic Disord 2020; 22 (2): 143-55

The role of EEG in patients with suspected epilepsy

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Received November 09, 2019; Accepted January 04, 2020

ABSTRACT – Despite the advances in imaging, EEG remains a critical test for the diagnosis of epilepsy. Not only can it confirm the diagnosis, but it can also clarify the type of epilepsy. There are many different types of EEG recordings depending on duration, the presence of video, and inpatient or outpatient setting, each with its pros and cons. Interictal epileptiform abnormalities are very specific to epilepsy, but they can be over-interpreted by inexperienced readers. In addition to diagnosis of epilepsy, EEG also has a role in the decision to discontinue treatment in seizure-free patients, and in assessing critically ill patients for possible status epilepticus and encephalopathies. EEG reports should be relatively standardized and clear to the clinician who requested the EEG.

Key words: EEG, epilepsy, indications, interpretation, report

For many years, EEG has been synonymous with "routine" EEG, a short recording without video. With the improvement of digital technology over the last 30 years, there are now many ways to perform EEG recordings.

Definitions (Benbadis, 2015)

– *Routine (or standard) EEG:* 20-30 minutes, usually without video (but can easily be added). Often this is performed with standard "activation procedures" that increase the yield for capturing interictal epileptiform discharges (IEDs) or even seizures. The most commonly used activation procedures are photic stimulation, hyperventilation and sleep deprivation (staying up late the night before);
– *Prolonged EEG (1-2 hours):* as for routine EEG above, this can be performed with or without video. Prolonged EEG may also mean extended recording in order to obtain sleep.
– *Ambulatory EEG*: outpatient recording, usually for 1-3 days but duration varies, with or without video;
– *Video-EEG monitoring*: this is usually assumed to be inpatient and prolonged, but really does not have to be either; it can be short or long, inpatient or ambulatory.

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doi:10.1684/epd.2020.1151

Competencies and learning objectives (Blümcke *et al.*, 2019)

- To determine who should receive EEGs for the diagnosis of seizures.
- To be familiar with sensitivity and specificity of EEG
- To understand the various types of EEG studies
- To interpret the report in the clinical context

– *Long-term monitoring*: this term is confusing because it only refers to duration, but it is often used *implying* the presence of video. It does not necessarily include video, and there is no definition of how many hours constitute "long term". It is usually associated with video recording even though the word "video" is not used;
– *Epilepsy monitoring* and *EEG monitoring* are general terms that specify neither what is monitored (video or not) nor for how long, and probably should not be used;
– The terms "*prolonged*" and "*long-term*" have no strict definition, so it is probably best to specify duration, that is, two hours, six hours, 24 hours, three days, and so on. Obviously, the longer, the better, as this increases sample time, but there are practical limitations.
With all these options and various combinations of duration and video or not, it is probably best to use specific descriptive terms. Monitoring using one type or another is arguably the main activity of referral epilepsy centres, be it for children or adults, and is now also performed in smaller hospitals and in the ambulatory setting.
In this article, we will discuss the following:
– The value of routine EEG for the diagnosis of seizures and epilepsy.
– The role of EEG in making decisions regarding antiseizure medication withdrawal.
– The added value of *prolonged* EEGs and *video*-EEGs.
– The use of EEG in the intensive care unit (ICU) setting.
– The interpretation of the EEG report.

The value of routine EEG for the diagnosis of seizures and epilepsy (*table 1*)

The routine EEG, lasting 20-30 minutes, is the most basic and inexpensive EEG test, and can support a diagnosis of epilepsy. Nonetheless, despite advances in both EEG and neuroimaging, the history is still the mainstay for the diagnosis (Amin & Benbadis, 2019). The principal objective of the routine EEG, in the diagnosis of epilepsy, is to capture IEDs.

Table 1. General indications for EEG (Beniczky *et al.*, 2017).

Epilepsy-related indications - clinical suspicion of epilepsy or seizure - reconsider the initial diagnosis of epilepsy - classification of a patient diagnosed with epilepsy - changes in seizure pattern - suspicion of non-convulsive status epilepticus - monitoring of status epilepticus - monitoring of seizure frequency - monitoring the effect of medications - considering stopping ASM therapy - presurgical evaluation - driver's license or flight certificate
Other differential diagnostic questions - psychogenic non-epileptic seizures - loss of consciousness - disturbance of consciousness - encephalopathy - encephalitis - dementia - cerebral vascular disease - paroxysmal behavioural changes - other psychiatric or behavioural symptoms - coma - brain death
Specific paediatric indications - genetic syndrome - metabolic disorder - regression - developmental problems
Follow-up EEG
Assessment of prognosis

Sensitivity of Interictal Epileptiform Discharges (IEDs)

In adult epilepsy centres, the sensitivity of an initial routine EEG to reveal IEDs ranges from 29 to 55% (Pillai & Sperling, 2006). IEDs should be distinct, standing out from the background, and usually appear as spikes, sharp waves and spike-wave complexes (St. Louis & Cascino, 2016). Depending on the type of epilepsy, the sensitivity of the routine EEG can vary. For example, patients with Lennox-Gastaut syndrome nearly always have abnormal routine EEG with IEDs, while a frontal lobe epilepsy patient may never have IEDs on interictal EEG. Other factors such as age, sleep deprivation, level of consciousness, focal vs generalized epilepsy, temporal versus extratemporal epilepsy, antiseizure

medications (ASM), seizure frequency, activation procedures, proximity of the EEG to recent seizure activity, and additional electrodes can also affect the sensitivity of routine EEG. Generally, the sensitivity of routine EEG is around 50% for the initial EEG and increases to 82-92% with repeated studies (Ajemone-Marsan & Zivin, 1970; Goodin & Aminoff, 1984; Salinsky *et al.*, 1987). Extended EEGs can also increase sensitivity. For example, the mean duration to an initial IED was 56 minutes in patients with temporal lobe epilepsy and 22 minutes in patients with a generalized epilepsy (Losey and Uber-Zak, 2008). Others found that only 36% of patients had IEDs within the first 20 minutes of long-term monitoring, while 89% had IEDs in the first 24 hours (Narayanan *et al.*, 2008). Other studies compared a repeat 30-minute EEG to extended two-hour EEG and found that the diagnostic yield is similar in patients with a previous normal routine EEG (Zabeen *et al.*, 2019).

Specificity of IEDs

The specificity of IEDs is very high in theory, with only "false positive" rates of 0.2-0.5% in adults and 1.9-3.5% in children (Pillai & Sperling, 2006; Amin & Benbadis, 2019). Unfortunately, this specificity is sabotaged in the real world due to the very common and under-reported problem of EEG over-interpretation (Benbadis & Lin, 2008; Benbadis, 2010; Benbadis, 2013; Kang & Krauss, 2019). The over-reading of EEGs occurs when a benign variant or artefact is misinterpreted as an IED (Benbadis & Lin, 2008; Benbadis, 2010; Benbadis, 2013; Kang & Krauss, 2019). Unfortunately, this leads to a common scenario encountered at epilepsy referral centres. About 25% to 30% of patients previously diagnosed with epilepsy, who do not respond to an initial ASM treatment do not have epilepsy (Amin & Benbadis, 2019). The perceived risk associated with not treating a possible case of epilepsy often leads to clinician misdiagnosis at a rate of 2% to 71% (Benbadis & Lin, 2008; Benbadis, 2010; Benbadis, 2013; Oto, 2017). Syncope and psychogenic non-epileptic attacks (PNEA) are the leading misdiagnosed conditions in adults and adolescents (Benbadis, 2007; Xu *et al.*, 2016), whereas the differential diagnosis is broader in children (Wyllie *et al.*, 2002). The "over-read" EEG is often the cause of the misdiagnosis of epilepsy even if the patient's history is not particularly suggestive of epilepsy (Amin & Benbadis, 2019). Reasons for the over-reading of EEGs include common misconceptions about the significance of "phase reversals", a lack of EEG training during neurology residency, and a history bias (Benbadis & Lin, 2008; Benbadis, 2010; Benbadis, 2013; Amin & Benbadis, 2019). Most over-read patterns are benign temporal sharp transients or wicket spikes (Benbadis & Lin, 2008; Benbadis, 2010; Benbadis, 2013). The benign variants typically occur during drowsiness and light sleep and do not disrupt the background rhythm, rather, the benign variants fade in and out of the normal background rhythm. The misdiagnosis of epilepsy has a significant impact on a patient's life with the initiation of an ASM and its associated side effects, lifestyle restrictions (*e.g.* driving restrictions), and the stigma of having a chronic illness (Benbadis & Lin, 2008; Benbadis, 2010; Benbadis, 2013; Oto, 2017).

EEG and ILAE definition of epilepsy

Since 2014, the ILAE classification (Fisher *et al.*, 2014; Fisher *et al.*, 2005 allows for the diagnosis of epilepsy after a single seizure if a patient has a greater than 60% risk of recurrence, rather than waiting for two unprovoked seizures > 24 hours apart. If a person had IEDs on EEG (or structural abnormality on neuroimaging), then the patient meets the criteria for diagnosing epilepsy. This decision is important in potentially determining the initiation of ASMs.
In patients with intellectual disability or structural brain lesions, the specificity of EEG is lower, since IEDs can be present even in patients who never had seizures (Ajemone-Marsan & Zivin, 1970). Therefore, in this setting, a history of at least one seizure may be required to diagnose epilepsy in patients with IEDs.

The value of EEG in the diagnosis and classification of the epilepsy type

IEDs captured on routine EEGs, if present, usually yield information that allows the classification of epilepsy (Koutroumanidis *et al.*, 2017a; 2017b). Interictal EEG alone can lead to error in epilepsy classification. For example, generalized spike-wave complexes may also be present in a patient with a focal seizure disorder causing bi-synchrony (St. Louis & Cascino, 2016). Thus, IEDs should always be interpreted in the context of the history and other findings.

The role of EEG in making decisions regarding antiseizure medication withdrawal

In patients with epilepsy, who are seizure-free for a long time (2-5 years) while taking antiseizure medication (ASM), one can consider withdrawing ASM to eliminate adverse events related to medication. However, relapse occurs in almost half of the patients (46%) (Lamberink *et al.*, 2017) and therefore it is important to estimate the risk of relapse in each patient, before making decisions on withdrawal of ASM.

Several studies suggested that the presence of epileptiform EEG discharges before ASM withdrawal is associated with relapse after withdrawal (Tatum *et al.,* 2018). A systematic review and meta-analysis, based on data extracted from 10 studies (1,769 patients in total) found that the presence of epileptiform discharges on the EEG recorded before withdrawal was an independent predictor of relapse: hazard ratio for seizure recurrence was 1.5 (95% confidence interval: 1.25-1.79) (Lamberink *et al.,* 2017). The presence of epileptiform discharges, together with other clinical variables, are the input information for a nomogram that can predict relapse with a concordance of 0.65 (95% confidence interval: 0.65-0.66) (Lamberink *et al.,* 2017).

The importance of epileptiform discharges for decisions on withdrawal also depends on the type of epilepsy. Patients with idiopathic (genetic) generalized epilepsy may be at significant risk of recurrence when persistent EEG abnormalities are present (Buna, 1998; Gavvala & Schuele, 2016). Conversely, in patients with self-limited epilepsy with centro-temporal spikes, the risk of relapse is low, even in spite of epileptiform EEG discharges (Lamberink *et al.,* 2017). In patients with pharmaco-resistant focal epilepsy, in the appropriate clinical setting such as after resective surgery, the presence of IEDs at six months after surgery suggests that seizures may recur after withdrawal of ASM (Jeha *et al.,* 2006).

The added value of prolonged EEGs and video

With ubiquitous digital technology, EEG is no longer just a routine 20-minute recording without video. As mentioned earlier, the variables (options) are: inpatient versus outpatient, prolonged versus short, with video versus without, and with provocation/activation versus without. Those are of course independent attributes, which do not necessarily have to go together. Consequently, there are many combinations possible and many types of studies, some more realistic than others.

Outpatient short EEG (no video)

This is usually referred to as "routine" EEG. This is the oldest and least expensive "default" method to obtain an EEG. The limitations of routine EEG are well known and obvious, and relate to low yield of intermittent abnormalities due to a short-time sample. For the diagnosis of seizures, as mentioned above, the yield of a single routine EEG increases with repeated EEGs, possibly up to 90% by the fourth EEG, but some patients with epilepsy will lack IEDs despite repeated EEGs (Salinsky *et al.,* 1987). Again, and importantly, the specificity of routine EEG (for epilepsy) is very high in theory, but in reality, is often quite low because of the (under-reported) problem of over-reading (Benbadis & Lin, 2008; Benbadis, 2010; Benbadis, 2013; Kang & Krauss, 2019). Nonetheless, despite obvious limitations, routine EEG is inexpensive and simple, and can be sufficient, even if normal, in most situations.

Outpatient short EEG with video

Virtually all EEG machines nowadays have a (digital) video recorder, so video should probably be added to any routine EEG, in case a clinical event is captured. If the purpose is mainly to capture the event in question for diagnosis, video-EEG can be short-term and have a high diagnostic yield. Appropriate in such situations would be, for example, patients with Lennox-Gastaut syndrome with multiple daily seizures, and other patients with daily events that are strongly suspected to be psychogenic, especially when combined with activation procedures (Benbadis *et al.,* 2004).

Outpatient prolonged EEG without video

This is commonly referred to as "ambulatory EEG". Because it is less expensive than inpatient EEG monitoring, ambulatory EEG can and has been used not with the intent of capturing an episode, but as an extension of routine EEG to increase the yield of capturing interictal discharges. That longer recordings increase the yield would seem logical, since we know that repeated routine EEGs certainly do (Salinsky *et al.,* 1987), but this has not specifically been studied. One situation where there may be no need for video is when episodic (seizure-like) symptoms are purely subjective, *i.e.* when there would be nothing visible on video.

Inpatient prolonged EEG without video

This was once performed commonly in ICU settings, but is now understandably rare since there is little justification for not adding a video, other than possibly cost.

The gold standard: prolonged video-EEG monitoring

For the epilepsy specialist, this is the gold standard and the starting point to care for patients whose seizures do not respond to basic treatment (Benbadis *et al.,* 2000; Benbadis *et al.,* 2004). The combination of prolonged EEG and video leads to an increase in yield of captured interictal discharges and, even more important, the ability to record the episodes in question.

In most cases (Benbadis *et al.,* 2000; Benbadis *et al.,* 2004; Benbadis *et al.,* 2009), video-EEG monitoring will provide answers to the following questions:
– Are the events epileptic or not?
– If not epileptic, what are they?
– If epilepsy, what type?
– If focal, where is the likely focus?
The principle and main goal of video-EEG monitoring is to record the episode in question, and obtain a clear diagnosis. It is critical to interpret the signs and symptoms (semiology based on video) in the context of the "ictal" EEG. Ictal EEG has limitations because it may be negative in some focal seizures, usually those without impairment of awareness. Hyperkinetic frontal lobe seizures can also fail to show ictal EEG seizure patterns. Ictal EEG may also be uninterpretable or difficult to interpret if movements generate excessive artefact. Analysis of the ictal semiology (*i.e.* based on video) is critical, and both ictal EEG and video must be interpreted in the context of one other to avoid pitfalls and diagnostic errors.

Does prolonged video-EEG monitoring need to be performed in the inpatient setting?

Until recently, it has been assumed that prolonged video-EEG monitoring had to be performed in the inpatient setting, and has in fact implied hospital admission. Similarly, until recently, the term "ambulatory EEG" has meant EEG monitoring without video (Tatum *et al.,* 2001; Schomer, 2006; Dash *et al.,* 2012; Maganti and Ruteki, 2013). However, with improvements in computer, storage, processing, and remote access, most functions of video-EEG can now be obtained in an ambulatory or home setting. So long as the video and EEG data are acquired, stored and displayed with good quality, where the data are acquired has become largely irrelevant.
Since the cost of outpatient prolonged video-EEG monitoring is significantly lower than inpatient, it is worth comparing the two in terms of advantages and disadvantages.

Inpatient setting
Advantages.
– Probably the single most compelling justification for the inpatient setting is the ability to reduce medications safely (to obtain a seizure) since patients have an intravenous line. Most patients who need video-EEG monitoring are on antiepileptic drugs. If antiepileptic drugs are to be reduced in order to record an event, this must be done in the inpatient setting, and preferably while the patient has intravenous access;
– The second major advantage of the inpatient setting is that it is a relatively controlled environment. While this is not guaranteed and sometimes fails, the likelihood that the patient will be on camera at the time of the event/seizure is much higher than in the ambulatory setting;
– Similarly, the likelihood of the patient or family pressing the alarm is likely higher in the inpatient setting;
– The ability to address technical problems with technologists during recording is easier, since technologists are on site;
– Activation procedures, such as hyperventilation, photic stimulation, sleep deprivation, and suggestion, are easily performed;
– An indirect but important advantage of the inpatient setting is that the interpretation will be performed by specialists who are credentialed by the hospital, which usually requires some board certification in clinical neurophysiology.

Disadvantages.
– The hospital is an artificial environment with little stress or activity, which is not the same as daily life, and occasionally patients will not have their events or seizures in this setting;
– An admission to the hospital may be inconvenient or not feasible due to home or family obligations, distance, time off work or relying on an accompanying person in the hospital;
– The availability in epilepsy monitoring units is often limited, and the wait time is often significant;
– The cost is artificially high for services that are either not medically necessary (*e.g.* 24-hour nursing, with frequent measurement of vital signs) or needs that are just as available at home (*e.g.* bed, meals and medications).

Ambulatory setting
Advantages.
– The ambulatory setting provides a typical environment and level of stress in which the episodes in question normally occur;
– Patients and families can benefit from the comfort of their own home;
– The cost is significantly lower;
– Availability is only limited by equipment, with no need for a hospital bed, and less wait time. For example, patients with clusters may not be able to wait days or weeks to undergo monitoring. On the other hand, if clusters are severe, they may be better served in the hospital setting.

Disadvantages.
– Probably the main limitation of ambulatory video-EEG, and the main reason it has not surpassed inpatient video-EEG, is the frequency with which patients are not on camera during the events in question. Although this has not been studied, a high proportion of such

studies are inconclusive and eventually an inpatient study is required. Situations that are appropriate for home video-EEG, with a high likelihood that the patient is caught on camera, include nocturnal events and homebound non-ambulatory patients (at home or facilities). The challenge of being on camera is, of course, critical when the symptoms in question would be visible on video (*e.g.* motor manifestations), but may be not as important when the symptom events are purely subjective, *i.e.* potential auras;
– A related issue is the patient and family's cooperation in identifying the events and pressing the alarm, which is probably more significant than during hospital monitoring;
– Another important limitation is that medications cannot be safely decreased, however, this does not apply when events are sufficiently frequent on medications so no reduction is needed;
– The ability to fix technical problems during recording is improving, as systems may now be monitored remotely, but this remains easier in the hospital setting;
– For outpatient studies, there is a potential danger that video-EEG is interpreted by untrained neurologists (as is currently the case for routine EEGs);
– In the vast majority of ambulatory studies with no recorded event, there is a potential for over-billing. When the video is recorded but no event is recorded, the current procedural terminology for the professional component should probably be coded without video.
Ultimately, video-EEG monitoring is an essential tool to manage patients with difficult seizures. In general, the hospital setting has definite advantages, and in certain cases, ambulatory video-EEG may obviate the need for an inpatient study.

The use of EEG in the ICU setting

In broad terms there are two types of EEGs that are obtained in an ICU. The first is the briefer diagnostic study that typically is recorded for less than an hour ("routine" EEG), and the second is the prolonged study which is performed continuously over many hours or days. Although EEG has been obtained in ICUs for decades (especially the shorter diagnostic studies), in the last 20 years there has been an explosion in the use of prolonged recordings. There have been several reasons for this growth. First and foremost is the improvement in technology, which has evolved from paper recordings that required the continuous presence of a technician with no easy ability to link video recordings to the EEG. Interpretation was a very slow process of manual page turning. The great increase in electronic storage capacity in computers, the improvement in processing speeds and the ability to synchronize EEG and video have made the prolonged studies much more efficient to record and review (Herman *et al.*, 2015a, 2015b). Further, it has become clear that many cases of altered mental status may be the result of unrecognized non-convulsive seizures or status. EEG then becomes an important tool for making the diagnosis and guiding treatment.
There are a number of reasons for obtaining an EEG in the ICU (Claassen *et al.*, 2013; Caricato *et al.*, 2018). The primary reason is to evaluate alterations in mental status when the cause is not clear, especially when clinically unrecognized seizures could be a factor (Drislane, 2013). A similar scenario is when a patient is demonstrating unusual, especially intermittent, behaviours, which could represent seizures (Hannawi *et al.*, 2016). Although a shorter diagnostic study is often sufficient to make the diagnosis if the behaviour of concern is recorded, there are times when a longer study is needed to make the diagnosis, and also to determine the effect of treatment. Another reason for ICU EEG is to determine the severity of dysfunction after an acute injury or in the presence of an encephalopathy, in order to assist with prognosis, although, with a few exceptions, prognostic determination in the acute post-injury period is not always accurate (Sutter and Kaplan, 2013). In these situations, prolonged recordings can also show whether the patient's condition is improving or worsening when there are few clinical signs to make that determination.
Using EEG to provide support for the clinical diagnosis of brain death has been common practice in diagnostic studies in the ICU, but the ICU is a setting that is confounded by many technical limitations (Stecker *et al.*, 2016). Unless required by local regulations or tradition, the added value of EEG in this situation is less clear.
There has also been growing use of EEG in the neonatal ICUs with an emphasis on several clinical situations (Abend *et al.*, 2013; McCoy and Hahn, 2013). The first is following an acute birth injury, especially if the child is undergoing a cooling protocol to minimize the severity of the injury. In this situation, there are several questions that are being addressed:
– how severe the injury may be;
– are there seizures in the acute setting;
– and is there improvement over the course of the study (typically several days).
A number of surgeons also request EEG monitoring after neonatal cardiac surgery to identify potential neurological consequences of the procedure. The interpretation of these studies is always complicated by the many changes in the EEG that are seen during normal development, such that a study that may be normal at 32 weeks of development is very abnormal at term. In addition, most of these children are sedated with a variety of drugs that will alter the EEG

significantly. In the ICU setting, the presence of sedative drugs must always be taken into consideration in the interpretation of the study to avoid over-interpreting the findings which may suggest a situation that is worse than the actual condition.

One of the problems in the interpretation of ICU studies is that the EEG patterns associated with different conditions, such as metabolic encephalopathies, degenerative disorders, and seizures, overlap. Therefore, placing the EEG within the broader clinical context for a particular patient is critical. Alternatively, one may say that interpreting the EEG based on waveform morphology, frequencies or evolving patterns alone without the clinical context has the potential for significant misinterpretations. In addition to the frequent lack of clearly distinguishing features that could separate the different aetiologies, there is also the problem of abundant artefacts. Although most artefacts are easy to identify, occasionally they are challenging. Features that are too focal, too regular, or too persistent may suggest the possibility of artefact. It is fair to consider whether a persistent, rhythmic, focal EEG pattern is artefactual. It often is.

The issue of artefact is also very important if one is relying on quantitative analysis of a digitized EEG signal. There are various methods of analysing the EEG based on frequency, amplitude and location, but these presentations of data are designed to compress multiple hours and channels of EEG into a summary of trends and events. These approaches can be very useful in the right setting, but unless one sees the raw EEG data that contributed to this summary analysis, one cannot be sure if the summary is based on artefact or true EEG.

Interpretation of the findings should always be placed in the clinical context. As noted above, there is significant overlap among the various EEG patterns and the evolution of those patterns and the underlying causes. As in most neurological conditions, the key issues for interpreting the EEG is the nature of onset of symptoms: sudden/acute, progressive over days or a few weeks, or chronic and progressive. In addition, such issues as whether the symptoms are monophasic, fluctuating or intermittent with returns to normal or near normal in between the symptoms of concern, are important in the interpretation, as is whether the symptoms are diffuse or focal.

The issue of aetiology is a key component in the interpretation. For example, continuously repetitive sharp and slow waves can be seen following a hypoxic injury, in metabolic or inflammatory encephalopathies, or in non-convulsive or myoclonic status epilepticus. Similarly, rhythmic slow activity can be seen in drug intoxication, metabolic encephalopathies or in non-convulsive status epilepticus. In the intensive care setting, patients frequently receive sedation. This issue must be taken into consideration, because, depending on the nature and depth of sedation, the EEG appearance can mimic anything from the electrocerebral silence of brain death to the increased drowsiness and associated mild slowing that could be confused with a mild congenital encephalopathy.

In understanding the results from an ICU study, it is important to be clear why the study was obtained. It is also important to take special situations into consideration, such as the developmental age of a neonate, as the EEG changes rapidly over weeks in that age group. It is very common for patients in the ICU to receive sedating medications, and these drugs can cause major changes in the EEG patterns. The doses and any changes must be taken into account in any prolonged study. These medications also affect the patient's mental status and motor activity, which must always be considered when evaluating the results of the study.

The interpretation of the EEG report

The EEG report needs to be concise but informative (Koutroumanidis *et al.*, 2017a; 2017b). There are variations on the information that will be included depending on the study, *i.e.* routine EEG versus prolonged EEG and the question asked, but here are basic general rules and standards (Koscer *et al.*, 2005; ACNS, 2006; Kaplan and Benbadis, 2013; Kane *et al.*, 2017). The report should include information regarding technical aspects, description of the EEG findings, classification and interpretation.

Technical aspects of the EEG

– Identification of artefacts;
– Location of where the study was obtained *i.e.* laboratory, epilepsy unit, ICU, patient floor, or ambulatory;
– Presence of skull defects;
– Duration of the study and whether video recording was obtained;
– Determination of whether the EEG is uninterpretable.

Description of the EEG findings

– Description of normal (if present) background activities as a function of age, state and reactivity. The dominant background activity should be described when a person is alert, relaxed and the eyes are closed, and include features in the posterior, central and anterior head regions. It should be followed by description of the emergence of patterns related to reactivity and to sleep states. There should be a statement whether the recording is organized with an adequate "anterior-to-posterior voltage gradient" when there is a steadily increasing amplitude of waveforms demonstrable from anterior to posterior

regions during wakefulness. It is recognized that EEGs obtained in patients with altered mental status may not include normal rhythms. This should be clearly stated;
– Description of background abnormalities including: lack of normal rhythms and abnormal state changes or reactivity; lack of expected patterns for age and state waveforms, amplitude asymmetries or fast rhythms; continuous or intermittent polymorphic or rhythmic slowing; and whether these findings are focal, multifocal or diffuse;
– Presence or absence of epileptiform discharges. If these are present, there should be a detailed description of morphology including presence or absence of stereotypic features, frequency, localization and periodicity, with identification of the interval;
– Presence or absence of "events" of interest and associated EEG findings establishing or refuting the diagnosis of a seizure, number of events, adequate EEG and clinical description of the events and whether all the captured events were similar or not. There is probably no need to repeat the descriptions if all events are the same;
– Presence of patterns associated with coma *i.e.* burst suppression patterns alpha or beta coma patterns;
– Description of any EEG findings after an intervention captured during the EEG recording;
– Any changes in cardiorespiratory functions if recorded, and their effect on the EEG.

Classification

Depending on the findings described above, the EEG can be classified as follows:
– Normal for age and state;
– Abnormal with a specific list of the identified abnormalities;
– Technically difficult - an EEG limited by factors outside the control of the technician, such as lack of cooperation by the patient or an unfriendly electrical environment. A repeat examination may be suggested if clinically indicated;
– Technically unsatisfactory - technically unsatisfactory refers to an EEG limited by factors within the control of the technician, such as failure to try to eliminate electrode artefacts. A repeat examination should be performed.

Interpretation

The EEGer should use the interpretation section to make concise statements tying the findings to the information that is available in the request form, *i.e.* the clinical context and the question asked. For each abnormal finding, an explanation and a possible clinical correlation should be included in a meaningful way. The EEG may confirm or argue against the referring physician's clinical impression. If it argues against, the referring physician will use this information to focus on other possible diagnostic testing. If the recording that is interpreted is a routine EEG, the EEGer may suggest other EEG-related tests (with the caveat "if clinically warranted" mentioned), such as a sleep-deprived EEG, or ambulatory or prolonged video-EEG monitoring study. The EEGer should not recommend any treatments based on the EEG.
The EEG report should be signed and dated. For prolonged monitoring, especially in a hospital setting, daily reports may be needed. □

Key points

- The sensitivity of routine EEG for epilepsy is 50-80%.
- The specificity for interictal epileptiform discharges is high (>90%), except for the under-reported problem of over-reading.
- When present, interictal epileptiform discharges usually help determine the type of epilepsy (syndrome).
- The presence of epileptiform EEG discharges is one of the independent predictors of relapse, yet it needs to be interpreted in the clinical context.
- EEG contributes to the risk assessment before making decision on withdrawal of ASM in seizure-free patients, hence this is an indication for recording EEG.
- There are different types of EEG recordings, for different purposes.
- The most definitive test to clarify a seizure type is video-EEG recording of the events in question.
- An EEG in the ICU is a useful tool for evaluating the cause of altered mental status and unusual behaviours when the cause is not clear.
- Prolonged ICU EEGs can provide an overview of the progress of the underlying disease and provide insight into the effect of treatment.
- Very different conditions can result in very similar ICU EEG patterns, so it is important to consider all of the possible causes.
- The EEGer should use the interpretation section of the report to make concise statements, tying the findings to the information that is available in the request form. For each abnormal finding, an explanation and a possible clinical correlation should be included in a meaningful way.
- Age, sleep states, medications and events of interest are key variables that must be taken into account when the report is prepared.
- The EEGer should always comment on technical issues that may hinder the interpretation of the EEG.

Disclosures

Dr. Benbadis is a consultant for Bioserenity (DigiTrace), Brain Sentinel, Cavion, Ceribell, Eisai, Greenwich, LivaNova, Neuropace, SK biopharmaceuticals, Sunovion; a member of the Speakers bureau for Eisai, Greenwich, LivaNova, Sunovion; a member of the Epilepsy Study Consortium; and has received grant support from Cavion, LivaNova, Greenwich, SK biopharmaceuticals, Sunovion, Takeda, UCB, Xenon and royalties as an author or Editor for Emedicine-Medscape-WebMD, UpToDate. He is also a member of the Editorial Board for Epilepsy.com (Epilepsy Foundation) controversy section, Emedicine-Medscape-WebMD, Epileptic Disorders, Epilepsy and Behavior, Expert Review of Neurotherapeutics.
Dr. Beniczsky is a consultant for UCB Pharma, Eisai, BIAL, GW Pharma, Philips, Brain Sentinel and Epihunter.
Dr. Bertram is a speaker for UCB.
Dr. MacIver received a grant support from Neuropace.
Dr. Moshé holds the Charles Frost Chair in Neurosurgery and Neurology and is partially funded by grants from NIH U54 NS100064 (EpiBioS4Rx), and NS43209, US Department of Defense (W81XWH-13-1-0180 and W81XWH-18-1-0612), and the Heffer Family and the Segal Family Foundations, and the Abbe Goldstein/Joshua Lurie and Laurie Marsh/Dan Levitz families. He is an Associate Editor for Neurobiology of Disease and is on the Editorial Board for Brain and Development, Pediatric Neurology and Physiological Research. He receives from Elsevier an annual compensation for his work as Associate Editor for Neurobiology of Disease, and royalties from two books he co-edited. He receives consultant's fees from UCB, Mallinckrodt and Pfizer.

Appendix

IFCN Glossary.
Kane N, Acharya J, Beniczky S, *et al*. A revised glossary of terms most commonly used by clinical electroencephalographers and updated proposal for the report format of the EEG findings. Revision 2017. *Clin Neurophysiol Pract* 2017; 2: 170–185.
Open access link: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6123891/

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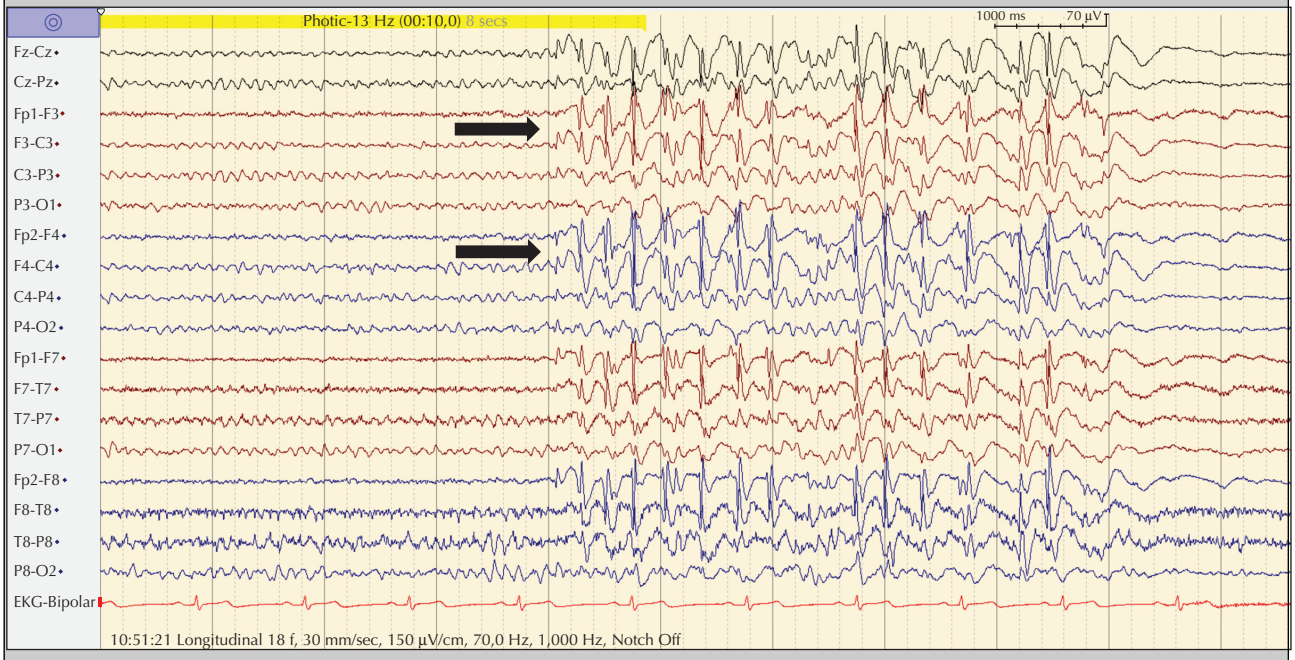
Case studies

Case 1

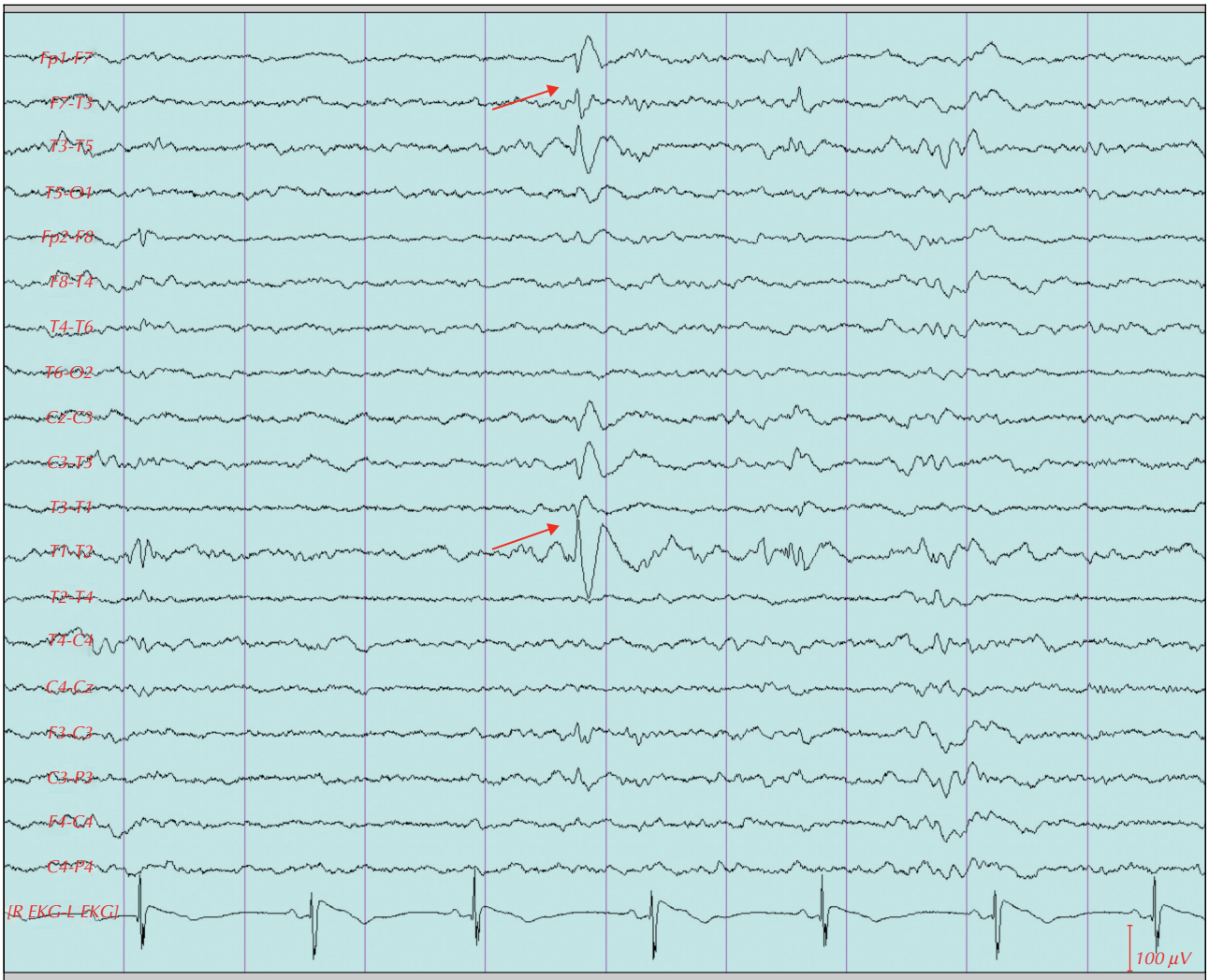
A 17-year-old adolescent girl had a generalized tonic-clonic seizure when having breakfast with her parents, who witnessed the episode. There was no history of previous seizures, jerks or staring. Cognition and neurological examination were normal. A maternal aunt had been diagnosed with epilepsy, and is currently seizure-free on lamotrigine.
A standard EEG recording was requested on suspicion of epilepsy. The EEG recording (*figure 1*) showed irregular, 3-4-Hz, bilateral-synchronous (generalized) spike/polyspike and slow-wave discharges, both unprovoked and precipitated during intermittent photic stimulation and drowsiness.



The EEG abnormalities, in the clinical context, suggest that the patient has idiopathic (genetic) generalized epilepsy. Although the patient had only a single, witnessed seizure, the clear-cut epileptiform EEG abnormalities indicate a risk of seizure recurrence at >60%, hence the patient fulfills the diagnosis, according to the ILAE definition.

Case 2

A 63-year-old man presented with a one-year history of unusual episodes. He had no warning and suddenly experienced an arrest of activity and was unresponsive. The family reported that he also picked at his clothes and pursed his lips. This lasted for about a minute and then he was confused for 10-15 minutes before returning to normal. He was referred for clarification of the diagnosis, with a concern of transient ischaemic attacks vs seizures.
A standard EEG (*figure 2*) revealed left temporal sharp waves.



The EEG abnormalities strongly support a diagnosis of focal epilepsy from the left hemisphere, likely temporal.

TEST YOURSELF

(1) Which is true regarding interictal epileptiform discharges (IEDs) on a routine EEG?

A. IEDs are present in over 90% of epilepsy patients
B. IEDs have no value in determining the type epilepsy
C. IEDs demonstrate high specificity in theory, but not in practice due to the common over-interpretation of normal variants
D. A normal routine EEG excludes the diagnosis of epilepsy

(2) In patients who are seizure-free on antiseizure medication (ASM), when considering withdrawal of the ASM:

A. EEG should not be recorded, because ASM can be withdrawn even when patients have IEDs.
B. EEG is an independent predictor, so risks can be assessed based on EEG alone.
C. EEG is useful only when considering withdrawing ASM in children.

D. EEG is useful only when considering withdrawing ASM in patients with focal epilepsy.
E. Presence of IEDs increases the risk of recurrence after ASM withdrawal, but this needs to be weighed together with the clinical data.

(3) Which is true of routine (standard) EEG for the diagnosis of epilepsy?
A. It is very sensitive.
B. It is poorly specific.
C. Errors in interpretation (over-reading) are common.
D. It typically requires two hours of recording.

(4) Which is false regarding prolonged video-EEG monitoring?
A. Provides a diagnosis in the majority of cases if the event in question is recorded.
B. Must be performed in the hospital.
C. Can record interictal epileptiform abnormalities even if no events are recorded.
D. Is an expensive procedure.

(5) EEG in the ICU:
A. Results is a precise diagnosis.
B. Provides an overview of the severity of an encephalopathy.
C. Is required for the diagnosis of brain death.
D. Is not affected by medications.

(6) The value of a prolonged ICU EEG relates to the fact that:
A. It can show trends in the underlying disease over time.
B. Once started, it requires little effort on the part of the technicians.
C. Requires no clinical information to interpret.
D. Recording artefact is easy to identify.

(7) Sedative medications during an ICU EEG:
A. Have a uniform effect on the EEG, independent of drugs.
B. Need only be noted as being used.
C. Should only be used to suppress seizures in status epilepticus.
D. May vary in effect based on dose, so changes must be identified.

(8) The EEG is reported as technically difficult if:
A. The patient does not fall asleep.
B. No events of interest occur.
C. Artefacts are present beyond the control of the technician such as lack of cooperation by the patient or an unfriendly electrical environment.
D. The recording contains artefacts that the technician fails to eliminate.
E. All of the above

(9) The description of epileptiform discharges in the EEG report:
A. Should avoid committing to a specific localization.
B. Should include location, frequency, relation to state, and provocation methods.
C. Should not be correlated with background abnormalities.
D. Should not use standardized terminology.
E. All of the above.

(10) A neonatal EEG:
A. Is not technically possible.
B. Should include only events of interest.
C. Should include the exact age including post presumed conception, and postnatal age and appropriate recording of sleep states.
D. Cannot be interpreted.
E. All of the above.

Note: Reading the manuscript provides an answer to all questions. Correct answers may be accessed on the website, www.epilepticdisorders.com, under the section "The EpiCentre".