CEEG INTERPRETATION

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Introduction

One of the most challenging arenas of EEG interpretation involves assessment of continuous EEG recordings in critically ill patients. With the rapidly expanding use of cEEG in the ICU, more and more neurologists are being called upon to assume responsibility for these complex interpretations. However, there are many unique aspects of ICU EEG interpretation that set it apart from review of conventional routine EEG studies and require additional skill and knowledge.

EEG Background

Background dysfunction can be described as mild, moderate or severe depending on the degree of slowing present. Mild cortical dysfunction typically presents as disruption of the posterior dominant rhythm as alpha activity is replaced by 4-7 Hz theta frequencies. Moderate dysfunction is typically manifested by a mixture of theta and polymorphic delta slowing with preservation of reactivity while more severe encephalopathy consists of high voltage delta slowing with a paucity of fast frequencies and is usually associated with significant subcortical as well as cortical pathology. EEG patterns suggestive of more profound dysfunction include burst-suppression pattern and low voltage, non-reactive delta slowing.

Description of background should not be confined to frequency analysis alone but should include additional features that can be helpful in determination of prognosis. Amplitude as measured in bipolar montage can be described as normal (>20uv), attenuated (<20uV) or suppressed (<10uV). Amplitude asymmetry may signify underlying focal cortical dysfunction but can also be seen with extra-axial fluid collections such as subdural hematoma or scalp edema. Focal background attenuation can be an important diagnostic sign as a recently described pattern of regional attenuation without delta activity (RAWOD) was found to be indicative of large acute ischemic strokes. On the other hand, skull defects are common in the neurocritical care population and result in a “breach rhythm” of focal *increase* in amplitude with superimposed fast frequencies.

Reactivity is an integral part of any EEG study, particularly in comatose patients. Progressive auditory and noxious stimuli should be presented with documentation of the time and strength of stimulus. Reactivity is represented by a change in frequency and/or amplitude of the background (either increased or paradoxically decreased). It is important to note that the presence of EMG activity alone does not constitute reactivity. Finally, the presence of normal sleep architecture can be an important prognostic sign and should be noted.

Specific coma patterns that have historically been associated with prognostic significance include alpha and spindle coma. Alpha coma consists of diffuse, invariant alpha activity and was first described in patients with brainstem lesions and later in post anoxic coma. Hence, prognosis of patients with alpha coma has traditionally been regarded as poor. However, more recent evidence suggests that that the underlying etiology of coma and presence of reactivity are primary determinants of outcome. Hence, alpha coma in the setting of toxic-metabolic encephalopathy carries far better prognosis than following hypoxic injury and amongst those with hypoxic injury, a reactive alpha coma pattern suggests better outcome than non-reactive. Spindle coma consists of theta or delta background with frequent bursts of diffuse 9-14 Hz spindle activity and can be seen in a variety of CNS insults. Although prognosis in patients with spindle coma is also determined largely by underlying etiology, the majority of patients with this pattern have been shown to have relatively good prognosis with the exception of those with diffuse anoxic brain injury.

A common indication for cEEG monitoring is detection of seizures and determination of prognosis following cardiac arrest. Background patterns are highly variable ranging from generalized background slowing to complete suppression and electrographic seizures and status epilepticus are common. The introduction of therapeutic hypothermia has raised many questions regarding the accuracy of EEG for outcome prediction.

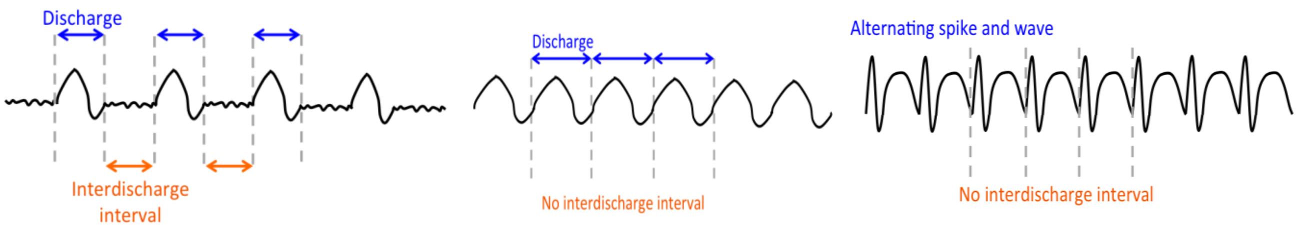
However, several retrospective series still support the following patterns to be predictive of poor outcome in patients who have undergone therapeutic hypothermia following cardiac arrest: absence of reactivity burst suppression, myoclonic status epilepticus and complete suppression.

Rhythmic and Periodic Patterns

Perhaps one of the most challenging aspects of cEEG interpretation involves accurate assessment of periodic and rhythmic patterns. The terms “triphasic waves”, “FIRDA” and “PLEDs” were initially described based upon routine 20 minute EEG recordings. These terms are quite familiar to most EEGers and have historically been associated with specific clinical scenarios. However, only recently has a classification system been developed to ensure standardized description to allow for improved accuracy in clinical reporting as well as systematic analysis of the true clinical significance of these patterns in critically ill patients undergoing cEEG. The ACNS Standardized Critical Care EEG Terminology was originally published in 2005 and has undergone several modifications with the most recent version published and adopted in 2012. The terminology describes periodic or rhythmic patterns <= 4Hz or spike-wave patterns <3 Hz and is based upon two “Main Terms” that are used to describe pattern location (Main Term 1) and pattern type (Main Term 2).

Options for Main Term 1 include generalized, lateralized (includes bilateral synchronous patterns that are asymmetric), bilateral independent and multifocal (rare). Main term 2 pattern types include the following: (1) Periodic Discharges (PD) - repetition of a waveform with uniform morphology and an inter-discharge interval in between, (2) Rhythmic Delta Activity (RDA) - repetition of a waveform of uniform morphology and NO interval in between and (3) Spike-Wave or Sharp-Wave (SW) – spike or sharp wave always followed by a slow wave in an alternating pattern.

Example of Periodic Discharge, Rhythmic Delta Activity and Spike-Wave:



After a pattern is assigned a designation of Main Term 1 and 2, there are options for additional modifiers to further describe elements such as frequency, amplitude, prevalence, duration, sharpness, polarity and whether the pattern is stimulus induced. An important feature of many of these patterns is the presence of superimposed fast (F) or rhythmic (R) activity which render the pattern more “ictal” appearing. Therefore a modifier of “Plus (+) F and/or R” can be added. In addition, patterns can be described as to whether they evolve, fluctuate or remain static. Evolving would be defined as 2 unequivocal changes in frequency morphology or location in the same direction while fluctuating is defined as 3 or more changes in frequency, morphology or location but in different directions such as patterns that alternate from 1 Hz to 1.5 Hz to 1 Hz and back to 1.5 Hz. Note that a pattern that is clearly evolving but never faster than 4 Hz would still qualify as a periodic or rhythmic pattern; even if it is also deemed clinically to represent an electrographic seizure (see below). Finally, to standardize description of “triphasic waves”, a modifier for triphasic morphology can be added which signifies a waveform with two or three phases, each phase longer than the previous and the positive phase of highest amplitude. In addition, anterior-posterior or posterior-anterior lag can be designated (>100 msec from A-P or P-A).

The table below illustrates how the standardized terminology is used to classify some common patterns seen in encephalopathic patients. Note that the “E” designating these patterns definitely epileptiform has been removed to avoid a clinical correlation that may or may not be accurate.

Original Term	Main Term 1	Main Term 2	Modifiers	New Terminology
GPEDs	Generalized (G)	Periodic Discharge (PD)		GPD
PLEDs	Lateralized (L)	Periodic Discharge (PD)		LPD
FIRDA	Generalized (G)	Rhythmic Delta Activity (RDA)	Frontally predominant	GRDA, frontally predominant
Triphasic Waves	Generalized (G)	Periodic Discharge (PD)	Triphasic morphology	GPD, triphasic morphology

Due to expanding use of the critical care EEG monitoring terminology, several studies have been able to enhance our knowledge of specific clinical correlations of these patterns. One example is a case control study matching 200 patients with generalized periodic discharges (GPDs) to 200 patients without this pattern. “GPEDs” were previously regarded as a pattern most commonly seen following cardiac arrest and associated with poor prognosis, but not necessarily associated with seizures. However, this study demonstrated that patients with GPDs had a significantly higher incidence of non-convulsive seizures and non-convulsive status epilepticus but were not independently associated with worse outcome. Gaspard and colleagues compared patients with lateralized rhythmic delta activity (LRDA) compared to a control population with either no periodic or rhythmic patterns or with lateralized periodic discharges (LPDs, formally “PLEDs”). This study demonstrated that patients with LRDA had a similar incidence of clinical and electrographic seizures as the patients with LPDs. This is an important finding considering that the high incidence of seizures associated with LPDs has been clearly established, yet prior to this study, the clinical significance of LRDA was unknown.

Electrographic Seizures

The most common indication for cEEG is for the detection of seizures. Since it has been well documented that clinical manifestations are either subtle or absent in the critically ill, precise EEG interpretation is paramount. The electrographic presentation of seizures in this population is distinct from the typical patterns seen in the epilepsy monitoring unit. Classic evolving fast frequency rhythmic activity is uncommon. Instead, low frequency, slowly evolving patterns, that can be very focal are more often encountered. In addition, ictal patterns can be difficult to differentiate from an already abnormal EEG background, particularly when periodic or rhythmic patterns are present. Therefore, criteria for the definition of an electrographic seizure in the critically ill have been proposed.

Minimum duration of 10 seconds and one of the following:

1. Repetitive spikes or sharp waves at least 3Hz

2. Rhythmic discharges >1 Hz and unequivocal evolution in frequency, morphology or location

3. Repetitive spikes or sharp waves <3 Hz and significant clinical improvement or appearance of normal EEG pattern after administration of a rapidly acting anti-epileptic drug. **NOTE**: periodic and rhythmic discharges are often attenuated or abolished following administration of benzodiazepines without clinical improvement or return of normal EEG. This response alone does not confirm the pattern was ictal.

However, despite proposed criteria, it is becoming increasingly evident that a clear distinction between EEG patterns that are definitively ictal vs. inter-ictal is often not feasible based on EEG evaluation alone and treatment trials with benzodiazepines are often equivocal. Therefore, ambiguous patterns are often referred to as the “ictal-interictal continuum”. These patterns pose particular diagnostic and treatment challenges and require careful clinical correlation and often ancillary testing to look for concordant evidence of neuronal irritability or injury.

One unique scenario is the presence of lateralized periodic discharges (LPDs) that present with time locked focal motor movements contralateral to the discharge focus. In addition, LPDs can be associated negative symptoms such as aphasia or hemiparesis that can be more difficult to recognize and requires detailed bedside evaluation. In these situations, the periodic discharges are usually regarded as ictal even if the above criteria for an electrographic seizure are not met. However, while it is common practice to treat ictal periodic discharges, there is no evidence to date that abolishing them improves outcome.

Finally, differentiating non-convulsive seizures from non-convulsive status epilepticus is another area of uncertainty. The current clinical definition of status epilepticus of a clinical seizure lasting greater than 5 minutes or recurrent seizures without regaining consciousness in between is difficult to apply patients who are already comatose at baseline. Some have suggested reverting to the prior definition of 30 minutes of continuous seizure activity as a definition of electrographic SE in the critically ill. However, this does not take into account the fact that a large portion of seizures in this population are not continuous but intermittent and periodic. Others have proposed the concept of "seizure burden" to measure not only the cumulative duration of seizure activity but also the spatial extent to which seizures propagate. To date, consensus has not been reached and further work is still needed, particularly in regards to the impact on neuronal injury and outcome following non-convulsive seizures and/or status epilepticus of various durations. In the meantime, a detailed, descriptive approach as to the timing, duration and extent of seizure propagation provides more useful information to the clinical team as opposed to more arbitrary labels of "status" or "not status".

Artifacts

One of the more challenging aspects of cEEG interpretation is differentiation of cerebral activity from the many artifacts present in the ICU environment. For this reason, concurrent video monitoring is essential. However, even with excellent video recording (which is not always the case), artifacts can still be misinterpreted. The two major categories of artifacts are physiological and electrical/mechanical. Physiological artifacts arise from within the patient's body and include eye movements, EKG, EMG and movement induced EEG changes. Some physiological artifacts are particularly accentuated by reviewing at high sensitivities which is often required in this population. In particular, pulse and ballistocardiographic artifact are often not appreciated at standard sensitivity settings but can mimic monomorphic delta activity when viewed at 3 uV/mm.

Electrical/mechanical artifacts are derived from the plethora of machines and devices used in the ICU environment including ventilators, bed percussion, dialysis, Swan-Ganz catheters, suction and CPR, not to mention the most common; electrode artifacts. Proper identification requires an awareness of the various devices being utilized, assessment of duration, onset and offset of the artifact, along with experienced pattern recognition.

Fortunately, EEG software to detect and remove common artifacts is under development which will allow better visualization of cerebral activity particularly for recordings that are largely obscured by artifact contamination. Nevertheless, the EEGer is still tasked with proper recognition and identification, particularly for less common artifacts, or serious misinterpretations can arise.

Conclusion

EEG interpretation in the ICU setting can be difficult and requires particular skill and experience. However, with knowledge of the wide variation of EEG patterns seen in these patients and their potential clinical correlates as well as good communication with the ICU team, EEG monitoring can be an invaluable tool in the care of critically ill patients.

References

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ACNS Standardized Critical Care EEG Terminology, guideline, pocket version and training module at www.acns.org/practice/guidelines#continuous_eeg_monitoring