OPEN

The role of the electroencephalogram and evoked potentials after cardiac arrest

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Purpose of review
In comatose cardiac arrest survivors, the electroencephalogram (EEG) is the most widely used test to assess the severity of hypoxic–ischemic brain injury (HIBI) and guide antiseizure treatment. However, a wide variety of EEG patterns are described in literature. Moreover, the value of postarrest seizure treatment is uncertain. Absent N20 waves of short-latency somatosensory-evoked potentials (SSEPs) are a specific predictor of irreversible HIBI. However, the prognostic significance of the N20 amplitude is less known.

Recent findings
The increasing adoption of standardized EEG pattern classification identified suppression and burst-suppression as 'highly-malignant' EEG patterns, accurately predicting irreversible HIBI. Conversely, continuous normal-voltage EEG is a reliable predictor of recovery from postarrest coma. A recent trial on EEG-guided antiseizure treatment in HIBI was neutral but suggested potential benefits in specific subgroups. A prognostic approach based on the amplitude rather than on the presence/absence of the N20 SSEP wave recently showed greater sensitivity for poor outcome prediction and added potential for predicting recovery.

Summary
Standardized EEG terminology and quantitative approach to SSEP are promising for improving the neuroprognostic accuracy of these tests. Further research is needed to identify the potential benefits of antiseizure treatment after cardiac arrest.

Keywords
cardiac arrest, coma, electroencephalogram, prognosis, short-latency somatosensory-evoked potentials

INTRODUCTION

More than 250 000 patients are resuscitated each year from out-of-hospital cardiac arrest (OHCA) in Europe [1]. Of those who achieve return of spontaneous circulation (ROSC) and are admitted to an ICU, more than 80% are in a coma because of hypoxic–ischemic brain injury (HIBI). HIBI is the most common cause of mortality or severe disability after cardiac arrest, and assessing its severity is essential in postresuscitation care. The electroencephalogram (EEG) and the short-latency somatosensory-evoked potentials (SSEPs) are among the most accurate tests to evaluate HIBI [2▪]. In addition to providing prognostic information, the EEG is also used to identify and guide the treatment of seizures associated with HIBI.

ELECTROENCEPHALOGRAM

The EEG signal is generated by the summation of postsynaptic potentials in the spatially aligned cortical pyramidal cells. The EEG is also modulated by subcortical structures, that is, the thalamus [3]. The cortical synaptic transmission is very sensitive to brain ischemia. The EEG is suppressed within seconds after cerebral blood flow stops or falls below 10 ml/100 g/min [4], even if residual EEG activity

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KEY POINTS

- A standardized EEG classification ensures an optimal communication among researchers and clinicians.
- Standardized EEG patterns predict both good and poor outcome in comatose survivors of cardiac arrest.
- Although a recent trial showed that a stepwise treatment of Rhythmic or periodic patterns (RPP) does not improve neurological recovery or survival after cardiac arrest, some patients with RPPs have good outcome and may potentially benefit from active treatment.
- A quantitative approach to SSEP has a potential to improve sensitivity for poor outcome prediction in HIBI and to identify patients destined to neurological recovery.

may persist for a few minutes [5]. Importantly, in patients with reversible HIBI, the EEG may remain suppressed for several hours after ROSC and recover subsequently (Fig. 1). This underlines the importance of timing when assessing EEG in HIBI.

HOW TO READ THE ELECROENCEPHALOGRAM

The raw EEG signal is complex, making visual interpretation difficult and prone to subjectivity and interrater variability [6]. For this reason, using a standardized EEG classification is essential for communication among clinicians and to interpret and summarize the results of clinical studies. In 2021, the American Society of Clinical Neurophysiology (ACNS) released its updated guidelines that standardize the definitions of EEG patterns [7▪▪]. The most important terms for the interpretation of postarrest EEG are described in Table 1, and the most important EEG patterns are described in Fig. 2. The EEG consists of the background activity and superimposed activity if present.

ELECROENCEPHALOGRAM BACKGROUND ACTIVITY

The background activity is the ongoing underlying summation of rhythms. A normal EEG background is continuous, reactive to external stimuli, and has a normal voltage (above 20 μV). A very low-amplitude EEG activity (below 10 μV) is called *suppression*. When suppression periods constitute more than half of the recording and are alternating with bursts, the pattern is called burst-suppression. If consecutive bursts appear stereotyped according to strict criteria, the pattern is called burst-suppression with identical bursts (Fig. 2f) and its prognosis is very poor, even if occasional recovery has been reported [8].

DISCHARGES, SEIZURES, AND STATUS EPILEPTICUS

Common superimposed patterns in HIBI are epileptiform discharges and rhythmic or periodic discharges, sometimes fulfilling ACNS criteria for possible or definitive seizure activity. These patterns

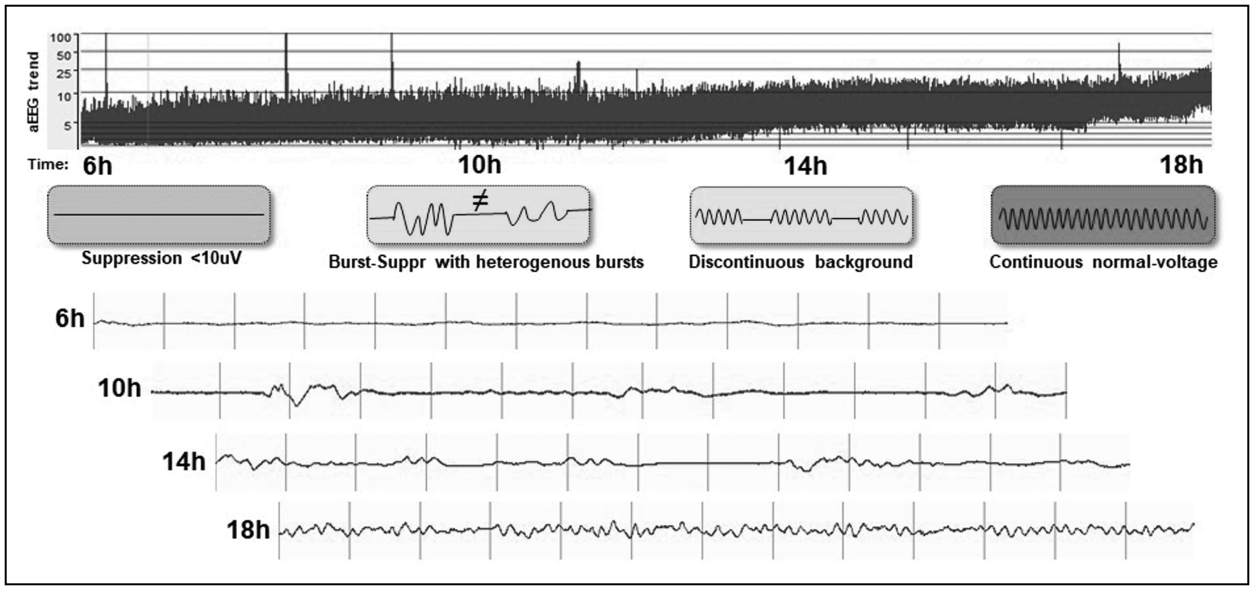

FIGURE 1. Favorable electroencephalogram development. Return of a continuous-normal voltage background within the first day predicted good prognosis in a 28-year-old patient with primary cardiac arrest (asystole). The patient woke up on day 5 post arrest and had a good outcome at 6 months follow-up.

Table 1. Summary of the electroencephalogram features of greater relevance for neuroprognostication after cardiac arrest, defined according to the 2021 ACNS terminology[a]

Feature	Definition
Background EEG	
Voltage	
Normal	All activity ≥20 μV
Low-voltage	Most or all activity <20 μV
Suppressed	All activity <10 μV
Continuity	
Continuous	Continuous EEG activity. Voltage may be normal or low-voltage.
Nearly continuous	Continuous EEG activity, but with occasional (1–10% of the record) periods of attenuation (lower amplitudes but >10 μV) or suppression (<10 μV).
Discontinuous	10–49% of the record consists of attenuation or suppression periods.
Burst-suppression	≥50% of the record consists of suppression periods alternated with bursts.
Identical bursts	The first part of consecutive bursts is identical/similar in most bursts.
Highly epileptiform bursts	Multiple epileptiform discharges or seizure patterns are seen within most bursts.
Suppression	All (>99%) of the record consists of suppression.
Reactivity	Reactivity is a change in cerebral EEG activity (amplitude or frequency) to auditory and/or noxious stimuli. The so-called stimulus-induced discharges, muscle artifacts, or eye blink artifacts do not qualify as reactive.
Superimposed activity (discharges and seizures)	
Rhythmic or periodic patterns (RPP)	Regular repetition of similar waveforms with (periodic) or without (rhythmic) a discernible interdischarge interval between consecutive waveforms. (A rhythmic pattern often has higher frequency compared with a periodic pattern.)
Rhythmic delta activity	Rhythmic uniform slow activity (≤4 Hz). (rarely fulfils criteria for possible seizure)
Rhythmic spike-and-wave or sharp-and-wave/rhythmic epileptiform discharges	Rhythmic spikes (duration <70 ms) or sharp waves (>70 ms) consistently followed by slow waves in a regularly repeating and alternating pattern (spike-wave-spike-wave-spike-wave). (This represents a rhythmic epileptiform pattern)
Periodic discharges	Regular repetition of similar discharges of any kind with a discernible inter-discharge interval between consecutive waveforms. (This pattern may have epileptiform morphology but can also constitute for instance, triphasic/blunt waves.)
Sporadic epileptiform discharges	Irregularly appearing (nonrhythmic and nonperiodic) sharp waves and spikes. Prevalence may vary from rare to abundant.
Definitive electrographic seizure activity	Epileptiform discharges appearing at high frequency (>2.5 Hz) or any pattern with spatiotemporal evolution for >10 s. (Discharges in a 'definitive seizure' are typically rhythmic epileptiform discharges or, less commonly, periodic discharges.)
Possible electrographic seizure activity	Epileptiform discharges at a frequency between 1 and 2.5 Hz for >10 s. (Discharges in 'possible seizure' are typically periodic discharges or less commonly abundant sporadic epileptiform discharges or rhythmic delta activity if additional criteria are fulfilled.)
Electroclinical seizure activity	(a) Definite clinical correlate time-locked to a pattern of any duration (also <10 s) or (b) electroencephalographic and clinical improvement after treatment trial with antiseizure medication. (If a 'possible electrographic SE' is accompanied by a clinical correlate, it is upgraded to 'definitive electroclinical SE'.)
Definitive, possible or electroclinical status epilepticus	Definitive, possible or electroclinical seizure activity appearing continuously >10 min or intermittently constituting >20% of an hour.

EEG, electroencephalogram; SE, status epilepticus.
[a]Ref. [6].

have both prognostic and therapeutic implications in HIBI.

Epileptiform discharges are spikes or sharp waves (i.e. pointed peaks), sometimes associated with a slow wave (Fig. 2h). Although epileptiform discharges have a high specificity to indicate epilepsy in otherwise healthy people, this is not the case in the critically ill, where isolated epileptiform discharges can be a clinically irrelevant finding because of encephalopathy.

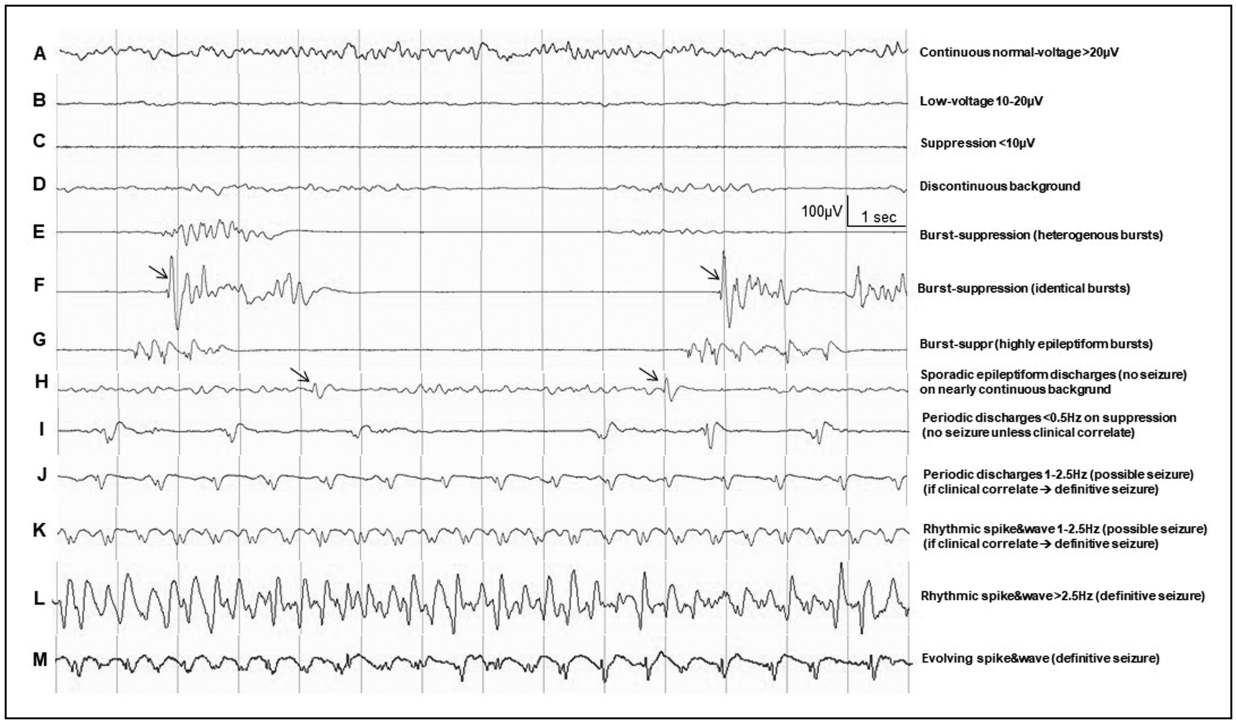

FIGURE 2. Electroencephalogram patterns of major interest in postanoxic coma.

If discharges appear repetitively in a regular fashion, they are called rhythmic or periodic patterns (RPPs). Rhythmic patterns are repetitive waveforms with no visible interval between consecutive waves, while periodic patterns have a clearly visible interval between consecutive waves and are often slower than rhythmic patterns (Fig. 2i–j).

From a purely EEG (electrographic) perspective, seizures are RPPs or series of discharges that last longer than 10 s and have a frequency above 2.5 Hz (Fig. 2l) and/or a spatiotemporal evolution. If they appear at a slower rate (1–2.5 Hz), they represent possible seizure activity [7▪▪,9]. Regardless of their rate or duration, EEG patterns with a clinical correlate (such as muscular jerks, eye deviation, and nystagmus) time-locked with the EEG activity are called electroclinical seizures (see Table 1). Accompanying clinical manifestation of seizures may be lacking, especially in the critically ill [10], where sedation and/or neuromuscular blockade may suppress motor activity.

Based on the ANCS terminology, seizures that appear continuously for more than 10 min or constitute greater than 20% of a 60 min period represent status epilepticus.

USING ELECTROENCEPAHLOGRAM FOR PROGNOSTICATION AFTER CARDIAC ARREST

EEG is the most used tool for assessing the severity of HIBI [11]. In addition, there is increasing evidence that specific EEG patterns also predict neurological recovery [12▪].

Suppression (with or without periodic discharges) and burst-suppression are ominous prognostic signs and are often referred to as 'highly malignant' patterns. There is substantial interrater agreement across blinded reviewers for these patterns if they are defined using the ACNS terminology [6]. In the targeted temperature management (TTM) trial, a total of 310 comatose resuscitated patients, at 28 participating sites, had a routine EEG recorded at a time-point corresponding to 2–4 days after ROSC in most patients [13,14]. Highly malignant patterns were observed in 83 (28%) patients, with only one patient achieving neurological recovery at 6 months [specificity 99%; 95% confidence intervals (95% CIs) 98–100]. A larger multicenter study from Ruijter *et al.*[15] on 850 patients showed similar findings. However, unlike the previous study, burst-suppression without highly epileptiform or identical bursts was defined as 'heterogeneous' burst-suppression (variable bursts) and was not included among highly malignant patterns. This 'heterogeneous' burst-suppression was associated with neurological recovery in a minority of patients, especially if recorded during the first 24 h after ROSC, during ongoing sedation and temperature control with hypothermia. In the TTM trial mentioned above, the only patient with good outcome had a 'heterogenous' burst-suppression during ongoing sedation. These findings

suggest that the accuracy of burst-suppression, or at least of its 'heterogeneous' phenotype, for predicting poor outcome is time-dependent and/or sedation-dependent. The 2021 guidelines on post-resuscitation care issued by the European Resuscitation Council (ERC) and the European Society of Intensive Care Medicine (ESICM) [16▪▪] suggest using highly malignant EEG patterns to predict poor outcome, but only after 24 h from ROSC.

In addition to the 'highly malignant' patterns, other EEG features may be associated with unfavorable neurological outcome. However, they are less specific, and for this reason, they are often referred to as 'malignant' or 'intermediate' patterns. They include a low-voltage, discontinuous, or unreactive background, or the presence of superimposed RPPs (Table 1). If two or more of these features coexist in the same recording, the likelihood of a poor neurological outcome is higher [14]. Interrater variability [6,17] and lack of standardization [14] limit the usefulness of reactivity testing for poor outcome prediction, but a reactive EEG indicates favorable prognosis.

Postanoxic status epilepticus is usually associated with poor neurological outcome. However, up to one-third of patients with status epilepticus have favorable EEG features or no other sign of extensive brain injury on clinical examination, neuroimaging, or blood biomarkers (Table 2), and about one-third of them can recover [18,19]. Most patients recovering from postanoxic status epilepticus receive antiseizure medications and prolonged intensive care, usually 1-2 weeks [18,19].

Table 2. Strategy to identify patients with a potential for recovery in status epilepticus

Characteristics/signs
Favorable electroencephalographic signs
Late start of electrographic SE (beyond the first day)
Start of electrographic SE from an already established continuous background and continuous background between discharges
Lack of highly malignant EEG-patterns
Discharges with a limited field close to the midline
Reactive EEG background
Other prognostic tools with no evidence of extensive brain injury
Preserved brain stem reflexes
Preserved SSEP N20 potentials
Low or moderately elevated biomarkers of brain injury in blood (i.e., neuron specific enolase)
Neuroimaging without signs of extensive brain injury

EEG, electroencephalogram; SE, status epilepticus; SSEP, somatosensory-evoked potentials.

TIME-DEPENDENCY OF ELECTROENCEPHALOGRAM PATTERNS FOR PROGNOSTICATION

The prognostic significance of various EEG patterns in patients undergoing temperature control with hypothermia changes between the first day (ongoing hypothermia and sedation) and after (normothermia and reduced sedation). This is illustrated in Fig. 3.

Although the specificity of 'heterogeneous' burst-suppression for predicting poor outcome increases after about 24 h from ROSC [15,20,21], the sensitivity of highly malignant patterns decreases over time, that is, they become progressively less common in patients with poor outcome [20,22]. On the other hand, seizures more accurately predict poor neurological outcome when they appear early (within the first day) after ROSC, while status epilepticus starting later has a less unfavorable significance [23], especially if superimposed on an already established continuous background [24,25]. Whether this is because of an intrinsic time-dependent evolution of the EEG patterns after HIBI or to a progressive decrease of the interference from sedation or hypothermia is uncertain.

In patients with good neurological outcome, the presence of an early, continuous, normal voltage and reactive EEG background is a strong predictor of awakening and good neurological function [22,26,27]. This pattern is also time-dependent, being most accurate to predict poor prognosis in the first 24 h after ROSC [28▪].

CAVEAT IN ELECTROENCEPHALOGRAM-BASED PROGNOSTICATION

A common concern when prognosticating to make decisions on the continuation of life-sustaining treatment is the risk of a falsely pessimistic prediction [29]. Although the interference of sedation on the prognostic accuracy of EEG has not been clearly demonstrated [14,21,30], its neurodepressant effects should not be underestimated, especially as propofol is concerned [21]. Propofol can induce burst-suppression [31], even if this occurs at higher doses than those generally used for sedation in the ICU. Recently, consensus has shifted towards fever prevention (target temperature 37.5 °C) rather than temperature control with hypothermia for neuroprotection in patients with HIBI [32]. This may potentially lead to a reduced use of sedation after ROSC in the future.

Like all other predictors, the EEG patterns should be interpreted considering the clinical context and in combination with other prognostic signs, using a multimodal approach [16▪▪,33], to reduce the risk of a falsely pessimistic prediction.

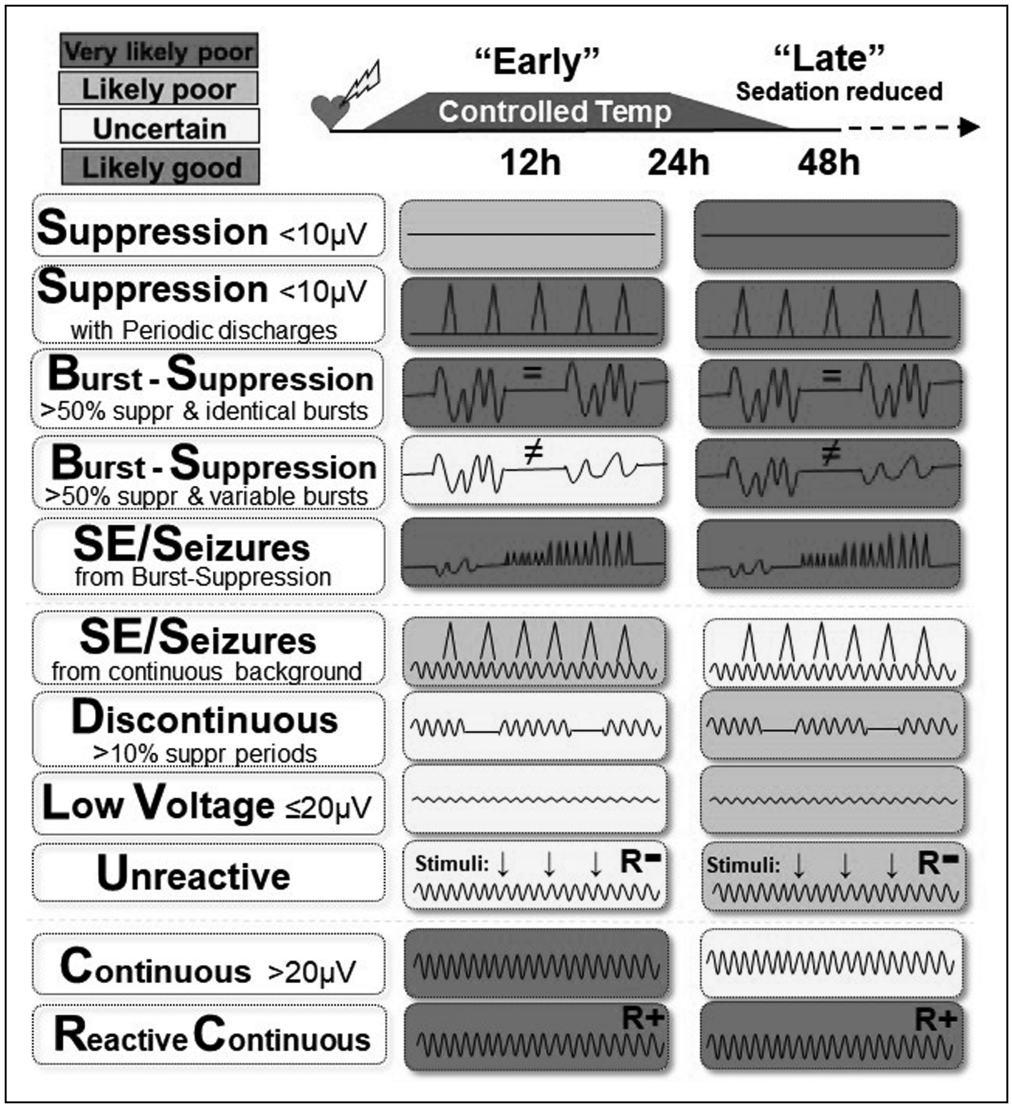

FIGURE 3. Time-dependency of prognostic electroencephalogram patterns after cardiac arrest. Simplified scheme on the prognostic value of various EEG patterns in the early phase during ongoing sedation and temperature control and during a later phase when sedation is reduced or stopped. The prognostic ability of patterns is not only categorized according to data in the literature but also considered the opinions of the authors. 'Very likely poor' = specificity to predict poor outcome close to 100% (>95% in nearly all studies). 'Likely poor' = specificity still high but often less than 95%. 'Uncertain' = no definite prognostic value. 'Likely good' = strongly associated with good outcome. EEG definitions are made according to the ACNS version 2021. EEG, electroencephalogram; SE, electrographic status epilepticus.

USING ELECTROENCEPHALOGRAM TO DETECT AND TREAT SEIZURES

The detection and treatment of postanoxic seizures is the other main indication for recording EEG after cardiac arrest. RPPs occur in up to 30% of patients who are comatose after ROSC [18,19]. Most of these are periodic discharges, while definitive seizures are infrequent. Myoclonus is the dominating clinical manifestation but generalized tonic–clonic seizures may also occur [34]. EEG is needed to rule out the presence of seizures as they are often nonconvulsive because of the use of sedatives and muscle relaxants. On the other hand, EEG is crucial to confirm that a clinical seizure is epileptic as seizure mimics are common in the ICU [35].

Because seizures cause metabolic stress potentially exacerbating HIBI [36,37], an EEG-guided pharmacological treatment aimed at suppressing seizures might be beneficial. However, there is no definite evidence that antiseizure drugs improve the outcome in HIBI. The recent open-label TELSTAR trial randomized 172 comatose resuscitated patients with RPPs to receive a stepwise antiseizure treatment or standard care [38▪▪]. In 135 of 172 (78%) patients,

RPPs consisted of generalized periodic discharges (i.e. possible seizure activity), whereas definitive electrographic seizures were recorded in only 17 (10%) patients. Although in the treatment arm, complete suppression of RPP within 48 h was obtained in 56% of the patients vs. 2% in the control arm, the rates of poor neurological outcome or death did not differ (90 vs. 92%, respectively). The study also showed that all patients with a discontinuous or suppressed EEG background died regardless of the superimposed patterns, confirming results of recent systematic reviews [20]. Subgroup analysis showed a nonsignificant higher rate of favorable outcome associated with treatment in patients with electrographic seizures or evolving patterns, while the opposite trend was observed with generalized periodic discharges. Further studies are needed to clarify if seizures are simply a marker of severe HIBI or a target for treatment and, in the latter case, in which categories treatment can be beneficial.

STRATEGIES FOR ELECTROENCEPHALOGRAM RECORDING AND ANALYSIS

Full-montage routine EEG for 20–30 min is the most common type of EEG used after HIBI [11] being widely available during office-hours at most hospitals. Continuous EEG (cEEG) monitoring is increasingly used in HIBI as it facilitates assessment of EEG evolution after ROSC and increases sensitivity for detection of potentially treatable seizures in HIBI compared with a late routine EEG [39]. However, there is no evidence that cEEG improves outcome of HIBI [40]. Full-montage, 21-channel cEEG is resource-consuming and labor-intensive and strategies to simplify cEEG recording and interpretation have been explored. Reduced electrode montages may be applied and maintained by trained ICU nurses. Their analysis by EEG-specialists showed similar sensitivity for detecting seizures and similar prognostic ability compared to full-montage cEEG in HIBI [41]. Automated EEG analysis techniques can quantify prognostically relevant features and use this information in artificial neural networks to provide prognostic guidance. In one study, automated EEG analysis predicted neurological outcome with similar accuracy than standard visual EEG assessment by trained experts [42]. However, their superiority over conventional EEG analysis remains to be established [43].

ROLE OF EVOKED POTENTIALS

Evoked potentials are an electrical activity recorded at a specific time window after a standardized stimulus. Although several types of evoked potentials exist, only short-latency SSEPs of the upper limb have been extensively used to assess HIBI. These are obtained after stimulation of the median nerve at the wrist. The most important SSEP parameter after cardiac arrest is the N20-wave. This is generated in the primary somatosensory cortex in the parietal lobe where thalamocortical cells have synaptic connections with the superficial and deep pyramidal cell layers located in the posterior wall of the central sulcus. The presence of N20-wave requires both an intact cortex and an intact thalamus and provides insights on the restoration of the normal thalamocortical coupling after HIBI [44].

In patients who are comatose after cardiac arrest, a bilateral absence of the N20 SSEP waves (Fig. 4a) has a very high specificity for prediction of poor outcome. Rare reports of neurological recovery despite a bilaterally absent N20 were most explained by an unreadable tracing rather than a true absence of the N20 wave [45]. The voltage of the evoked potential signal is much lower than that of EEG or muscular activity, and for this reason, use of neuromuscular blocking drugs and careful avoidance of artifacts are recommended when SSEPs are recorded for prognostication [16▪▪].

SSEP sensitivity for predicting poor outcome is relatively low, rarely exceeding 30% [20]. However, histopathological evidence [46] has shown that the N20 SSEP amplitude (N20Amp) is inversely related to the severity of HIBI, which provide grounds for using N20Amp to predict outcome after cardiac arrest. Figure 4 provides an example of different SSEP amplitude patterns that can be found in patients with HIBI. In recent clinical studies, a strategy combining a low N20Amp with the conventional dichotomous classification (i.e. presence or absence of the N20 wave) yielded a sensitivity for prediction of poor outcome of up to 70% [47,48▪,49]. However, these studies used different N20Amp cut-off values (generally in the range of 0.5–1 μV) to dichotomize their findings. In addition, the N20Amp was evaluated at different time points within 12–72 h after ROSC, and there is evidence that the N20Amp varies over time in the first days after arrest [50,51]. Finally, while a bilateral absence of the N20 wave is unlikely to result from sedation [52], the N20Amp is reduced by up to 40% under Midazolam anesthesia [53]. At present, no definitive cut-off can be recommended to predict poor outcome in HIBI using N20Amp. Interestingly, limited evidence shows that a high N20Amp may predict good outcome early after ROSC [48▪,54].

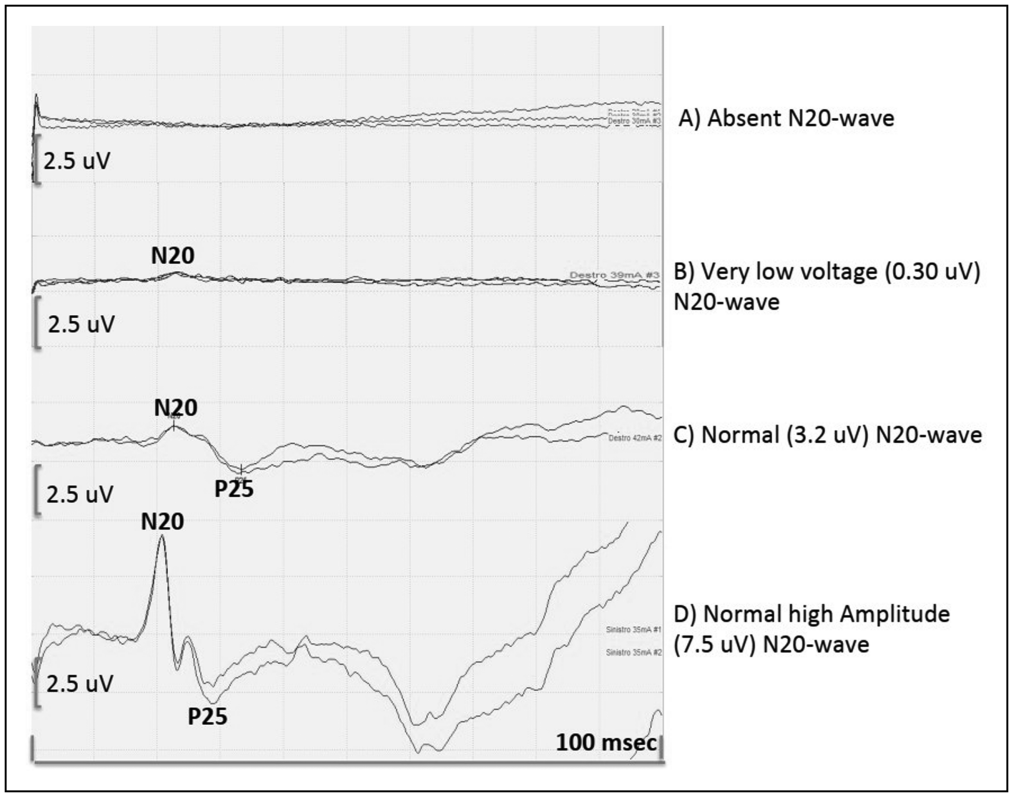

FIGURE 4. Short-latency somatosensory-evoked potentials after stimulation of the median nerve in patients with hypoxic–ischemic brain injury. Only cortical responses are shown (montage: parietal cortex contralateral to the stimulus referred to the frontal midline). From top to bottom, different SSEP patterns according to the severity of HIBI and outcome are shown. SSEP, somatosensory-evoked potentials.

CONCLUSION

EEG is widely used and a recommended neuroprognostication tool after cardiac arrest. EEG showing suppression or burst-suppression (highly malignant) accurately predict a poor neurological outcome at 24 h or later after ROSC. Conversely, an early continuous, normal-voltage EEG background predicts good outcome. EEG is also useful to detect seizures in HIBI and guide antiseizure treatment. Although seizures and status epilepticus after cardiac arrest portend a poor prognosis, they are still compatible with neurological recovery in a minority of patients. In patients with severe HIBI, the bilateral absence of the SSEP N20-wave is a highly specific sign of extensive and irreversible injury, but its sensitivity is low. In addition, recent but limited evidence shows that the amplitude of the N20 wave may provide additional prognostic information.

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Conflicts of interest

C.S. is Associate Editor of Intensive Care Medicine, member of the Editorial Board of Resuscitation and lead author or senior author of studies mentioned in this article. A.G. is senior author of studies mentioned in this article. E.W. is senior author of studies mentioned in this article.

REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:

- ■ of special interest
- ■■ of outstanding interest

1. Gräsner JT, Lefering R, Koster RW, *et al.* EuReCa ONE-27 Nations, ONE Europe, ONE Registry: a prospective one month analysis of out-of-hospital cardiac arrest outcomes in 27 countries in Europe. Resuscitation 2016; 105:188–195.
2. ■ Alkhachroum A, Appavu B, Egawa S, *et al.* Electroencephalogram in the intensive care unit: a focused look at acute brain injury. Intensive Care Med 2022; 48:1443–1462.

This extensive narrative review written by a group of major experts in the field describes the clinical applications of the electroencephalogram in intensive care.

3. Steriade M, Gloor P, Llinás RR, *et al.* Report of IFCN Committee on Basic Mechanisms. Basic mechanisms of cerebral rhythmic activities. Electroencephalogr Clin Neurophysiol 1990; 76:481–508.
4. Jordan KG. Emergency EEG and continuous EEG monitoring in acute ischemic stroke. J Clin Neurophysiol 2004; 21:341–352.
5. Matory AL, Alkhachroum A, Chiu WT, *et al.* Electrocerebral signature of cardiac death. Neurocrit Care 2021; 35:853–861.

6. Westhall E, Rosen I, Rossetti AO, *et al.* Interrater variability of EEG interpretation in comatose cardiac arrest patients. Clin Neurophysiol 2015; 126:2397–2404.
7. ■■ Hirsch LJ, Fong MWK, Leitinger M, *et al.* American Clinical Neurophysiology Society's Standardized Critical Care EEG Terminology: 2021 version. J Clin Neurophysiol 2021; 38:1–29.

Thiis updated edition of the ACNS terminology, originally published in 2013, represents a standard for the definition and the nomenclature of the EEG patterns in critical care.

8. Coppler PJ, Kusztos AE, Andreae M, *et al.* Awakening from post anoxic coma with burst suppression with identical bursts. Resusc Plus 2021; 7:100151.
9. Kane N, Acharya J, Benickzy 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.
10. Claassen J, Taccone FS, Horn P, *et al.* Recommendations on the use of EEG monitoring in critically ill patients: consensus statement from the neurointensive care section of the ESICM. Intensive Care Med 2013; 39:1337–1351.
11. Friberg H, Cronberg T, Dunser MW, *et al.* Survey on current practices for neurological prognostication after cardiac arrest. Resuscitation 2015; 90:158–162.
12. ■ Sandroni C, Cronberg T, Sekhon M. Brain injury after cardiac arrest: pathophysiology, treatment, and prognosis. Intensive Care Med 2021; 47:1393–1414.

Large narrative review (145 references) on pathophysiology and clinical management of HIIBI.

13. Backman S, Cronberg T, Friberg H, *et al.* Highly malignant routine EEG predicts poor prognosis after cardiac arrest in the Target Temperature Management trial. Resuscitation 2018; 131:24–28.
14. Westhall E, Rossetti AO, van Rootselaar AF, *et al.* Standardized EEG interpretation accurately predicts prognosis after cardiac arrest. Neurology 2016; 86:1482–1490.
15. Ruijter BJ, Tjepkema-Cloostermans MC, Tromp SC, *et al.* Early electroencephalography for outcome prediction of postanoxic coma: a prospective cohort study. Ann Neurol 2019; 86:203–214.
16. ■■ Nolan JP, Sandroni C, Bottiger BW, *et al.* European Resuscitation Council and European Society of Intensive Care Medicine guidelines 2021: post-resuscitation care. Intensive Care Med 2021; 47:369–421.

The 2021 Guidelines on Post-Resuscitation Care resulted from a wide expert consensus and a collaboration between the European Resuscitation Council and the European Society of Intensive Care Medicine. The section on prognostication after cardiac arrest is based on a systematic review of 94 studies (2013-2020).

17. Caroyer S, Depondt C, Rikir E, *et al.* Assessment of a standardized EEG reactivity protocol after cardiac arrest. Clin Neurophysiol 2021; 132:1687–1693.
18. Backman S, Westhall E, Dragancea I, *et al.* Electroencephalographic characteristics of status epilepticus after cardiac arrest. Clin Neurophysiol 2017; 128:681–688.
19. Rossetti AO, Oddo M, Liaudet L, Kaplan PW. Predictors of awakening from postanoxic status epilepticus after therapeutic hypothermia. Neurology 2009; 72:744–749.
20. Sandroni C, D'Arrigo S, Cacciola S, *et al.* Prediction of poor neurological outcome in comatose survivors of cardiac arrest: a systematic review. Intensive Care Med 2020; 46:1803–1851.
21. Sivaraju A, Gilmore EJ, Wira CR, *et al.* Prognostication of postcardiac arrest coma: early clinical and electroencephalographic predictors of outcome. Intensive Care Med 2015; 41:1264–1272.
22. Cloostermans MC, van Meulen FB, Eertman CJ, *et al.* Continuous electroencephalography monitoring for early prediction of neurological outcome in postanoxic patients after cardiac arrest: a prospective cohort study. Crit Care Med 2012; 40:2867–2875.
23. Westhall E, Rosen I, Rundgren M, *et al.* Time to epileptiform activity and EEG background recovery are independent predictors after cardiac arrest. Clin Neurophysiol 2018; 129:1660–1668.
24. Ruijter BJ, van Putten MJ, Hofmeijer J. Generalized epileptiform discharges in postanoxic encephalopathy: quantitative characterization in relation to outcome. Epilepsia 2015; 56:1845–1854.
25. Rundgren M, Westhall E, Cronberg T, *et al.* Continuous amplitude-integrated electroencephalogram predicts outcome in hypothermia-treated cardiac arrest patients. Crit Care Med 2010; 38:1838–1844.
26. Bongiovanni F, Romagnosi F, Barbella G, *et al.* Standardized EEG analysis to reduce the uncertainty of outcome prognostication after cardiac arrest. Intensive Care Med 2020; 46:963–972.
27. Scarpino M, Carrai R, Lolli F, *et al.* Neurophysiology for predicting good and poor neurological outcome at 12 and 72 h after cardiac arrest: the ProNeCA multicentre prospective study. Resuscitation 2020; 147:95–103.
28. ■ Sandroni C, D'Arrigo S, Cacciola S, *et al.* Prediction of good neurological outcome in comatose survivors of cardiac arrest: a systematic review. Intensive Care Med 2022; 48:389–413.

The only systematic review published to date on predictors of neurological recovery after cardiac arrest. It includes 37 studies, most of which are based on electrophysiology.

29. Geocadin RG, Callaway CW, Fink EL, *et al.* Standards for studies of neurological prognostication in comatose survivors of cardiac arrest: a scientific statement from the American Heart Association. Circulation 2019; 140:e517–e542.
30. Drohan CM, Cardi AI, Rittenberger JC, *et al.* Effect of sedation on quantitative electroencephalography after cardiac arrest. Resuscitation 2018; 124:132–137.
31. Huotari AM, Koskinen M, Suominen K, *et al.* Evoked EEG patterns during burst suppression with propofol. Br J Anaesth 2004; 92:18–24.
32. Sandroni C, Nolan JP, Andersen LW, *et al.* ERC-ESICM guidelines on temperature control after cardiac arrest in adults. Intensive Care Med 2022; 48:261–269.
33. Moseby-Knappe M, Westhall E, Backman S, *et al.* Performance of a guideline-recommended algorithm for prognostication of poor neurological outcome after cardiac arrest. Intensive Care Med 2020; 46:1852–1862.
34. Lybeck A, Friberg H, Aneman A, *et al.* Prognostic significance of clinical seizures after cardiac arrest and target temperature management. Resuscitation 2017; 114:146–151.
35. Benbadis SR, Chen S, Melo M. What's shaking in the ICU? The differential diagnosis of seizures in the intensive care setting. Epilepsia 2010; 51: 2338–2340.
36. Appavu B, Riviello JJ. Electroencephalographic patterns in neurocritical care: pathologic contributors or epiphenomena? Neurocrit Care 2019; 29:9–19.
37. Witsch J, Frey HP, Schmidt JM, *et al.* Electroencephalographic Periodic discharges and frequency-dependent brain tissue hypoxia in acute brain injury. JAMA Neurol 2017; 74:301–309.
38. ■■ Ruijter BJ, Keijzer HM, Tjepkema-Cloostermans MC, *et al.* Treating rhythmic and periodic EEG patterns in comatose survivors of cardiac arrest. N Engl J Med 2022; 386:724–734.

The only randomized controlled trial (TELSTAR) conducted to date on the treatment of seizures after cardiac arrest. This open-label trial compared a stepwise antiseizure treatment or standard care in 172 patients from 11 ICUs

39. Elmer J, Coppler PJ, Solanki P, *et al.* Sensitivity of continuous electroencephalography to detect ictal activity after cardiac arrest. JAMA Netw Open 2020; 3:e203751.
40. Urbano V, Alvarez V, Schindler K, *et al.* Continuous versus routine EEG in patients after cardiac arrest: analysis of a randomized controlled trial (CERTA). Resuscitation 2022; 176:68–73.
41. Backman S, Cronberg T, Rosén I, Westhall E. Reduced EEG montage has a high accuracy in the post cardiac arrest setting. Clin Neurophysiol 2020; 131:2216–2223.
42. Tjepkema-Cloostermans MC, da Silva Lourenço C, Ruijter BJ, *et al.* Outcome prediction in postanoxic coma with deep learning. Crit Care Med 2019; 47:1424–1432.
43. Bauerschmidt A, Eliseyev A, Doyle KW, *et al.* Predicting early recovery of consciousness after cardiac arrest supported by quantitative electroencephalography. Resuscitation 2021; 165:130–137.
44. van Putten M, Jansen C, Tjepkema-Cloostermans MC, *et al.* Postmortem histopathology of electroencephalography and evoked potentials in postanoxic coma. Resuscitation 2019; 134:26–32.
45. Bouwes A, Binnekade JM, Kuiper MA, *et al.* Prognosis of coma after therapeutic hypothermia: a prospective cohort study. Ann Neurol 2012; 71:206–212.
46. Endisch C, Westhall E, Kenda M, *et al.* Hypoxic-ischemic encephalopathy evaluated by brain autopsy and neuroprognostication after cardiac arrest. JAMA Neurol 2020; 77:1–10.
47. Oh SH, Park KN, Choi SP, *et al.* Beyond dichotomy: patterns and amplitudes of SSEPs and neurological outcomes after cardiac arrest. Crit Care 2019; 23:224.
48. ■ Scarpino M, Lolli F, Lanzo G, *et al.* SSEP amplitude accurately predicts both good and poor neurological outcome early after cardiac arrest; a posthoc analysis of the ProNeCA multicentre study. Resuscitation 2021; 163: 162–171.

The largest multicenter study conducted to date on the predictive value of N20 SSEP wave amplitude in postanoxic coma.

49. van Soest TM, van Rootselaar AF, Admiraal MM, *et al.* SSEP amplitudes add information for prognostication in postanoxic coma. Resuscitation 2021; 163:172–175.
50. Glimmerveen AB, Keijzer HM, Ruijter BJ, *et al.* Relevance of somatosensory evoked potential amplitude after cardiac arrest. Front Neurol 2020; 11:335.
51. Scarpino M, Lolli F, Lanzo G, *et al.* Do changes in SSEP amplitude over time predict the outcome of comatose survivors of cardiac arrest? Resuscitation 2022; 181:133-139.
52. Fossi S, Amantini A, Grippo A, *et al.* Continuous EEG-SEP monitoring of severely brain injured patients in NICU: methods and feasibility. Neurophysiol Clin 2006; 36:195–205.
53. Sloan TB, Fugina ML, Toleikis JR. Effects of midazolam on median nerve somatosensory evoked potentials. Br J Anaesth 1990; 64:590–593.
54. Endisch C, Storm C, Ploner CJ, Leithner C. Amplitudes of SSEP and outcome in cardiac arrest survivors: a prospective cohort study. Neurology 2015; 85:1752–1760.