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Electroencephalographic Monitoring in the Pediatric Intensive Care Unit

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Abstract Continuous electroencephalographic (CEEG) monitoring is used with increasing frequency in critically ill children to provide insight into brain function and to identify electrographic seizures. CEEG monitoring use often impacts clinical management, most often by identifying electrographic seizures and status epilepticus. Most electrographic seizures have no clinical correlate, and thus would not be identified without CEEG monitoring. There are increasing data showing that electrographic seizures and electrographic status epilepticus are associated with worse outcome. Seizure identification efficiency may be improved by further development of quantitative electroencephalography trends. This review describes the clinical impact of CEEG data, the epidemiology of electrographic seizures and status epilepticus, the impact of electrographic seizures on outcome, the utility of quantitative electroencephalographic trends for seizure identification, and practical considerations regarding CEEG monitoring.

Keywords Electroencephalogram · Electroencephalographic monitoring · Seizure · Status epilepticus · Intensive care unit · Critical care

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Introduction

Critically ill children now undergo continuous electroencephalographic (CEEG) monitoring with increasing frequency. CEEG monitoring provides real-time insight into brain function, highlights interval changes in brain function over time, and permits identification of electrographic seizures. Most electrographic seizures in critically ill children have no associated clinical signs and thus cannot be identified without CEEG monitoring. Electrographic seizures, particularly when frequent or prolonged, have been associated with worse outcome. This review summarizes current evidence regarding the utility of CEEG monitoring in critically ill children with a focus on the epidemiology of electrographic seizures and their impact on outcomes.

Electroencephalographic Monitoring—Indications and Impact

Common indications for CEEG monitoring in the pediatric intensive care unit (ICU) are summarized in Table 1. A recent survey of the use of CEEG monitoring in the pediatric ICUs of 61 large pediatric hospitals in the USA and Canada reported that the median number of patients who underwent CEEG monitoring per month increased by about 30 % from 2010 to 2011 [1•]. All centers reported using CEEG monitoring to help determine whether events of unclear origin were seizures. About 90 % of centers reported using CEEG monitoring in patients considered at risk of electrographic seizures, such as patients with altered mental status following a convulsion, altered mental status in a patient with a known acute brain injury, and altered mental status of unknown origin. About 50 % of centers reported using CEEG monitoring routinely in patients with specific diagnoses, such as following resuscitation from cardiac arrest or with traumatic brain injury [1•]. Similar data regarding indications were reported by a larger survey of 330 physicians addressing adult and pediatric ICU CEEG monitoring [2].

A recent study reported that CEEG monitoring data led to changes in clinical management in 59 % of 100 consecutive critically ill children with acute encephalopathy. These changes included initiating or escalating the use of anticonvulsants owing to seizure identification in 43 patients, determining that a specific event (movement or vital sign change) was not a seizure in 21 patients, thereby limiting inappropriate treatment with anticonvulsant medications, and obtaining urgent neuroimaging in three patients [3]. Although CEEG monitoring data often impact management, further study is needed to determine whether these management changes improve neurodevelopmental outcome.

Additional data regarding the impact of CEEG monitoring are available in adults. Studies of emergent electroencephalograms in critically ill adults have reported that they are often rated as clinically useful [4], contribute to establishing a diagnosis [5, 6], identify nonconvulsive seizures (NCS) and nonconvulsive status epilepticus (NCSE) [5, 7], identify seizure mimics [8], often guide clinical decisions [9], and often impact clinical management through initiation, escalation, or discontinuation of anticonvulsant medications [5, 10]. Although limited cost-effectiveness data are available, one study of 300 critically ill adults reported that CEEG monitoring costs were less than 1 % of the total hospitalization costs and that implementation of CEEG monitoring, likely in addition to other advancements in neurocritical care, was associated with a reduction in the length of stay and hospital costs [9].

Electroencephalographic Background and Prognosis

Assessment of the electroencephalographic (EEG) background provides useful prognostic information regarding the extent of brain injury in some critically ill children, and may identify interval changes in the degree of encephalopathy that could guide clinical management [11]. Although no individual neurodiagnostic modality has perfect

Table 1 Common indications for continuous electroencephalographic (*CEEG*) monitoring in the pediatric intensive care unit

Clinical scenarios	Specific diagnoses and situations
	Status epilepticus and refractory status epilepticus
Acute encephalopathy	Traumatic brain injury (accidental, nonaccidental)
With prior clinical seizures or status epilepticus	Hypoxic–ischemic brain injury (neonatal, cardiac arrest, near drowning)
With acute brain injury	Extracorporeal membrane oxygenation therapy
Unexplained	Acute ischemic or hemorrhagic stroke
Neuromuscular blockade, with acute brain injury	After cardiac surgery
Characterization of clinical events suspected to be seizures	After neurosurgery
Intracranial pressure management	Acute metabolic encephalopathy (sepsis, hepatic, renal)

prognostic value [12], the use of electroencephalography is appealing since it can be performed at the bedside, either continuously or repeatedly over time, and despite inter-rater agreement limitations, provides objective data. Information regarding the patient's clinical status and underlying diagnosis is essential to ensure that EEG background abnormalities are not attributable to sedating medications, scalp edema, or intracranial fluid collections.

Most of the data regarding EEG background and prognosis focus on children with acute hypoxic–ischemic brain injury, although some studies have focused on cohorts with more heterogeneous causes of brain injury [13–15]. Patients with more severely abnormal EEG backgrounds tend to have poorer short-term outcome than patients with mild/moderate background abnormalities. Certain EEG background features are known to have prognostic significance [13, 16–22]. Pediatric studies have reported that burst suppression [15, 16], excessive discontinuity [20], severe attenuation [15, 17], lack of reactivity [19, 20], and periodic or multifocal epileptiform discharges [15] are associated with unfavorable prognosis. Conversely, rapid EEG improvement over hours [21], reactivity [18], and normal sleep patterns [18, 22] are associated with favorable prognosis. A study of children treated with therapeutic hypothermia after resuscitation from cardiac arrest found that EEG backgrounds categorized as unreactive, discontinuous, burst-suppression, or lacking cerebral activity during the hypothermic or normothermic time periods were associated with unfavorable outcome, although not with perfect predictive value [14]. Thus, although some EEG background features appear to retain their predictive value during hypothermia, they still cannot be used in isolation for prognostication. Recently, a prospective study of 61 adults treated with therapeutic hypothermia following cardiac arrest reported that an unreactive or discontinuous EEG background pattern was associated with elevations in the level of serum neuron-specific enolase, suggesting that these early EEG abnormalities may reflect acute neuronal injury [23].

Electrographic Seizures: Definitions

Electrographic seizures are commonly defined as abnormal, paroxysmal EEG events that differ from the background activity, last longer than 10 seconds (unless associated with clinical signs), have a plausible electrographic field, and evolve in frequency, morphology, and spatial distribution [24, 25]. Electrographic seizures may be either *convulsive* or *nonconvulsive*. *Convulsive* (also termed electroclinical) seizures are electrographic seizures that are coupled with clinical manifestations. *Nonconvulsive* (also termed subclinical) seizures (NCS) are electrographic seizures that occur without clinical manifestations. *Subtle* seizures are electrographic seizures accompanied by clinical changes that are so mild that identification by careful observation in the absence of video-EEG monitoring would be very difficult. Although subtle seizures are technically convulsive seizures, since identification generally required CEEG monitoring, studies often group them with NCS.

Electrographic status epilepticus is commonly defined as uninterrupted electrographic seizures lasting 30 min or longer, or repeated electrographic seizures totaling more than 30 min in any 1 h period. Electrographic status epilepticus may be either convulsive or nonconvulsive. Although this definition allows classification, it is not based on any scientific evidence that those with a greater than 50 % seizure burden in 1 h fare worse than those with less than a 50 % seizure burden in 1 h. More broadly, NCSE has been broadly defined as an enduring epileptic condition with reduced or altered consciousness, behavioral, and vegetative abnormalities, or merely subjective symptoms such as auras, but without major convulsive movements [26].

Agreement among readers in identifying seizures is imperfect [27], especially when differentiating seizures from rhythmic or periodic patterns. The border between seizures and rhythmic or periodic patterns is often difficult to distinguish with certainty, and has been termed the "ictal–interictal continuum" [24]. Prolonged seizures may be particularly difficult to identify when their onset or offset is unclear, or when they blend with periodic or rhythmic discharges. This is a particular problem in children with preexisting epileptic encephalopathies, whose often highly abnormal electroencephalograms with abundant inter–ictal epileptiform discharges may resemble NCSE [28].

Epidemiology of Electrographic Seizures and Status Epilepticus

Electrographic seizures have been reported in 10-40 % of children who underwent CEEG monitoring in pediatric ICUs or emergency departments [29–38, 39•]. Most electrographic seizures are not accompanied by any clinical signs [29, 31, 35, 37, 38, 39•, 40, 41], even in nonparalyzed patients [29, 41], although some patients may exhibit subtle positive signs (i.e., automatisms, minor facial twitching, or blinking) or negative signs (i.e., behavioral and cognitive impairment) [42]. Risk factors for electrographic seizures have been identified. Children with altered mental status and a known acute neurologic disorder appear to be at greater risk of electrographic seizures than children who are comatose without an acute neurologic disorder [29, 35]. Children may be at increased risk of electrographic seizures compared with adults [43]. Clinical risk factors for electrographic seizures in children include younger age [29, 37], prior convulsive status epilepticus [37] or acute seizures [38,

40], structural brain injury [38, 40], including traumatic brain injury [37], and cardiac arrest [36]. EEG abnormalities associated with electrographic seizures in children include epileptiform discharges [37, 40], periodic epileptiform discharges [31], and lack of background reactivity [31]. Electrographic seizures have also been reported in children with specific conditions—acute ischemic stroke [44] and intracerebral hemorrhage [45]—and those undergoing extracorporeal membrane oxygenation [46, 47], but these studies did not perform CEEG monitoring in consecutive patients.

Children undergoing surgery for congenital heart disease are at risk of postoperative seizures. Clinical seizures have been reported in 6 % of 171 infants with dextro transposition of the great arteries [48] and in 18 % of 164 infants who survived congenital heart disease surgery requiring deep hypothermic circulatory arrest [49]. NCS are even more common than clinical seizures.[48, 50–54]. In the dextro-transposition study, electrographic seizures occurred in 20 % of 136 infants undergoing 48 h of CEEG monitoring, most of which had no clinical correlate [48]. In a second study, NCS occurred in 12 % of 183 children who underwent 48 h of CEEG monitoring after cardiac surgery [51]. A retrospective study of infants with congenital heart disease reported electrographic seizures in 6 % of 93 patients [52]. A study of children who underwent cardiac surgery with cardiopulmonary bypass and underwent EEG monitoring from intubation until 22–96 h after bypass reported electrographic seizures in 8 % of 36 children [53]. Finally, a study of 39 infants undergoing Norwood-type operations and continuous amplitude-integrated electroencephalography (aEEG) identified intraoperative seizures in 23 % of infants and postoperative seizures in 18 % of infants [54]. Risk factors for seizures in children with congenital heart disease include coexisting genetic defects, aortic arch obstruction, the presence of a ventricular septal defect, treatment with deep hypothermic circulatory arrest rather than continuous cardiopulmonary bypass, and prolonged deep hypothermic circulatory arrest [48–50].

Current management strategies for electrographic seizures occurring in critically ill children are varied. When surveyed, neurologists reported that the most commonly used medications used to manage NCS and NCSE were lorazepam, phenytoin/fosphenytoin, and levetiracetam. The second- and third-line medications were these same three in differing combinations, and there was substantial variability in practice. Most physicians reported escalating treatment for NCS and NCSE to include pharmacologic coma induction with intubation if seizures persisted after use of two or three standard anticonvulsants, for which the most commonly used medications were midazolam and pentobarbital [2]. This finding suggests that physicians are willing to take some medical risk in an attempt to terminate NCS and NCSE. Studies are needed to identify the optimal management regimen and then determine whether seizure identification and management improves outcome.

Duration of CEEG Monitoring

A survey of neurologists regarding their current practice of CEEG monitoring in adults and children (excluding neonates) indicated that most of them perform CEEG monitoring for 1–2 days if no seizures occur, although there was substantial variability in practice [2]. These monitoring duration decisions are likely based on studies of critically ill children undergoing clinically indicated CEEG monitoring which report that half of patients with seizures are identified in the first hour of monitoring, and about 90 % of patients with seizures are identified within the first 24–h of monitoring [29, 31, 32, 35, 37, 38, 40, 41, 55]. However, none of these studies performed CEEG monitoring for an extended duration in all patients. Had the CEEG monitoring continued for longer, seizures beginning later may have been identified in some patients.

Understanding the optimal duration of CEEG monitoring is important since seemingly small changes in CEEG monitoring duration have a substantial impact on resource needs [56]. Studies of children with specific types of acute brain injury and management may provide better focus. In a prospective study of 19 children undergoing therapeutic hypothermia after cardiac arrest, CEEG monitoring was initiated urgently and continued throughout the entire clinical protocol, including 24 h of normothermia. No children had electrographic seizures in the initial 6 h of monitoring (early hypothermia), one child had seizures in the next 6 h (early hypothermia), four children had seizures during the next 12 h (late hypothermia), and four children had seizures in the next 24 h (rewarming) [36]. Similarly, in neonates and infants who underwent repair of congenital heart disease, studies have reported electrographic seizures at a mean of 21 h after surgery [50, 51] with most seizures occurring 13–36 h after surgery [48]. These data suggest that with further study, CEEG monitoring duration may be tailored on the basis of a patient's age, clinical status, and cause of acute encephalopathy.

Electrographic Seizures and Outcome

Two questions central to assessing the utility of CEEG monitoring are (1) does the occurrence of electrographic seizures worsen outcome and (2) does identification and management of electrographic seizures improve outcome. The latter question has not yet been explored, but several recent studies have demonstrated an association between electrographic seizures and worse neurodevelopmental outcome in critically ill children. In a study of 75 children, NCS

were associated with higher mortality (15 % vs 8 %) and neurologic morbidity (31 % vs 4 %) [38]. In a second study of 204 critically ill comatose children and neonates, clinically evident seizures, electrographic seizures, a higher number and longer duration of electrographic seizures, and a worse EEG background score were associated with worse outcome. In a multivariable analysis, electrographic seizures were associated with worse outcome [odds ratio (OR) 15.4; 95 % confidence interval (CI) 4.7–49.7]. Furthermore, no children had favorable outcome if they had more than 139 seizures, more than 759 min of total seizures, or any individual seizure lasting longer than 360 min [39•]. A third study evaluated short-term outcome in 200 prospectively enrolled critically ill children who underwent CEEG monitoring for altered mental status and an acute neurologic problem. Eighty-four children (42 %) had seizures, which were categorized as electrographic seizures in 41 children (21 %) and electrographic status epilepticus in 43 children (22 %). In multivariable analysis, electrographic status epilepticus was associated with an increased risk of mortality (OR 5.1; 95 % CI 1.4–18) and a decline in pediatric cerebral performance category (OR 17.3; 95 % CI 3.7–80), whereas electrographic seizures were not associated with an increased risk of mortality (OR 1.3; 95 % CI 0.3–5.1) or decline in pediatric cerebral performance category (OR 1.2; 95 % CI 0.4–3.9). This suggests that higher seizure burden is independently associated with worse outcome [57•]. In a study of 154 children with status epilepticus, the presence of NCSE on initial electroencephalography was associated with increased risk of refractory status epilepticus and increased risk of poor long-term outcome. Although children with NCSE were not evaluated independently, more aggressive management was associated with a better treatment response and outcome [58].

Additional data on outcomes following seizures are available in the congenital heart disease population. A study of 164 infants with congenital heart disease with follow-up at 1 year identified abnormal neurological examination results in 11 of 15 patients (73 %) with postoperative seizures versus 41 of 99 patients (41 %) without seizures. Seizures were not associated with significantly lower scores on the Bayley Scales of Infant Development, except for frontal-onset seizures, which were associated with significantly lower mental development index scores compared with non-frontal-onset seizures [59]. In a study of aEEG in infants undergoing Norwood-type procedures, both intraoperative and postoperative seizures were associated with higher mortality, but were not associated with neurodevelopmental impairment [54]. An interesting set of studies have focused on children with dextro transposition of the great arteries who underwent an arterial switch operation with successive neurodevelopmental assessments. In the initial study of 155 of 171 infants, early postoperative electrographic seizures were associated with an increased risk of MRI abnormalities and with an 11.2 point reduction in the psychomotor development index of the Bayley Scales of Infant Development at 1 year follow-up [60]. In a follow-up study that extended to 2.5 years, children with seizures were also more likely to have lower psychomotor development scores [61]. By 4 years, children with seizures had significantly lower mean intelligence quotient scores and increased risk of neurological abnormalities [62]. Among 139 children evaluated at adolescence, postoperative seizures were the medical variable most consistently associated with worse outcome [63•].

Further data are available from several adult studies. NCSE of longer duration has been associated with worse outcome [25]. NCS have been associated with worse discharge outcome in adults with central nervous system infections [64], intracerebral hemorrhage expansion [65], and death or severe neurologic disability in adults in the medical ICU [66]. In adults with traumatic brain injury, NCS have been associated with increases in intracranial pressure and metabolic dysfunction [67], as well as with the development of ipsilateral hippocampal atrophy [68].

In summary, although the evidence for an association between seizures and worse outcome is growing, further study is needed to more precisely define the causal link between electrographic seizures and neurodevelopmental outcome, and to establish whether identifying and managing electrographic seizures improves outcomes.

Quantitative Electroencephalography for Electrographic Seizure Identification

Identifying seizures in critically ill children requires CEEG monitoring since most seizures in this population remain subclinical [29, 31, 35, 37, 38, 39•, 40, 41, 69]. Large numbers of critically ill children are at risk of NCS and stand to benefit from CEEG monitoring; however, the availability of CEEG monitoring remains limited because of a scarcity of expert neurophysiologists required to interpret raw CEEG monitoring data. Furthermore, although the electroencephalogram is recorded continuously, real-time review is seldom available [2], potentially resulting in delays between seizure occurrence, seizure identification, and treatment [70]. When CEEG monitoring is being used to screen for NCS, neurologists report that the CEEG monitoring data are reviewed once per day by 21 % of them, twice per day by 29 % of them, three or four times per day by 17 % of them, and almost continuously by only 18 % of them [2].

Quantitative electroencephalography (QEEG) algorithms separate the raw electroencephalogram into its component parts and compress several hours of EEG data onto a single display. This technique may permit more rapid analysis of

CEEG monitoring data by expert neurophysiologists and may facilitate seizure recognition by bedside caregivers without formal EEG training. Various QEEG tools, also referred to as digital trend analysis since QEEG trends are displayed over time [71], are now commercially available [72], but surveys indicate they are rarely used in current practice [2]

Three commonly used QEEG tools are aEEG, color density spectral array (CDSA) or compressed spectral array, and envelope trend. Because seizures typically contain higher-frequency and higher-amplitude activity than the background, seizures are apparent on aEEG and envelope trend as arch-shaped elevations in the tracing (reflecting increased amplitude), and on CDSA as bright bands of color (reflecting increased power at higher frequencies) (Fig. 1). Limitations of QEEG include missing seizures which are brief, of low frequency or low amplitude, or cover a small spatial area (particularly when a reduced number of channels are used). Conversely, high-amplitude or high-frequency artifacts may be misinterpreted as seizures on QEEG. Therefore, although QEEG may be used to identify regions of interest, review of the raw CEEG monitoring data remains important to minimize overinterpretation [71].

Amplitude-integrated electroencephalography (aEEG) is currently used for prognostication and seizure identification in many neonatal ICUs [73, 74], particularly among infants with hypoxic–ischemic encephalopathy undergoing therapeutic hypothermia [75]. Although novice aEEG users identify seizures with a specificity of below 50 %, experienced users can achieve a sensitivity and specificity of almost 85 % [76–79]. However, the sensitivity of aEEG for identifying individual seizures ranges from 12 to 96 % [77, 78, 80]. Despite these imperfections, the use of aEEG can improve the precision of neonatal seizure diagnosis [81] and reduce electrographic seizure burden [82]. However, with a false-positive rate using aEEG alone approaching 50 % [79], treatment decisions based solely on aEEG may result in overdiagnosis of seizures and overuse of anticonvulsants. The American Clinical Neurophysiology Society's guidelines on EEG monitoring in neonates state that aEEG is a "useful, initial complementary tool" to CEEG monitoring, which remains the gold standard [83].

Relatively few studies have investigated the utility of QEEG tools among critically ill nonneonatal children. In one study, the median sensitivity for seizure identification was 83 % using CDSA and 82 % using aEEG, but in individual EEG tracings the sensitivity ranged from 0 to 100 %. False-positive rates for both aEEG and CDSA were quite low [84•]. Another study applying compressed spectral array and envelope trend demonstrated that sensitivity for seizure identification depends on user experience, display size, and inherent seizure characteristics, such as seizure duration and spike amplitude [85]. In both of these studies, only brief training was required.

In summary, QEEG displays require minimal training to use and appear to have acceptable accuracy for seizure identification in some cases; however false negatives and false positives remain common enough that QEEG cannot yet replace review of the conventional EEG data. Further work is required to optimize QEEG display parameters, for example, by combining multiple QEEG trends to improve accuracy [85, 86]. Finally, although QEEG sensitivity remains imperfect, it must be remembered that inter-rater reliability for seizure identification using the "gold standard" conventional electroencephalogram is also imperfect [27, 87].

Practical Considerations

Performing CEEG monitoring in the pediatric ICU requires the collaboration of neurophysiologists, neurologists, EEG technologists, intensivists, nurses, and information

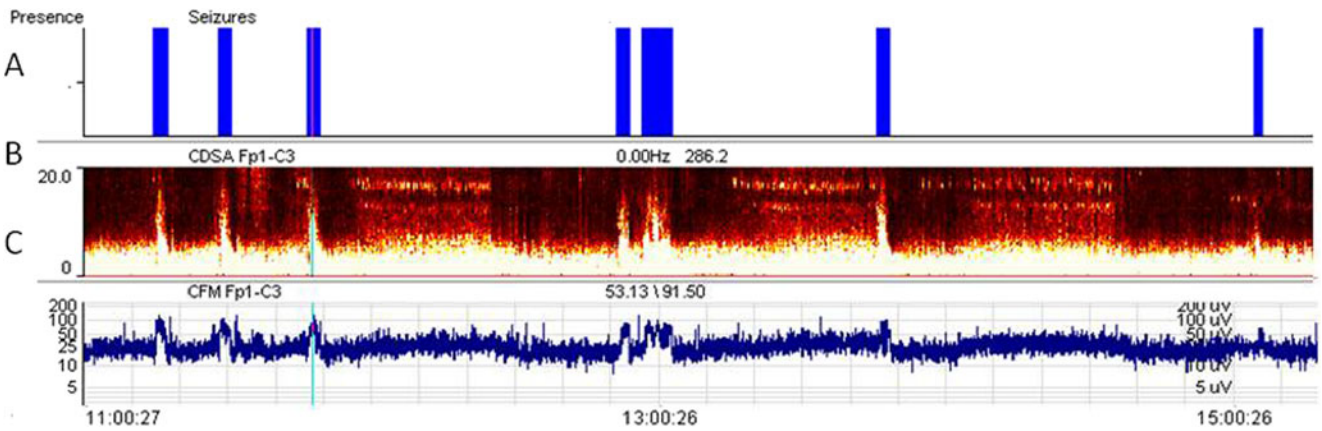

Fig. 1 Appearance of seizures on a 4-h quantitative electroencephalography display. **a** Timing of electrographic seizures identified by review of the raw electroencephalogram. **b** Color density spectral array (*CDSA*) trend depicts seizures as bright bands of color. **c** Amplitude-integrated electroencephalography (aEEG) trend depicts seizures as elevations in the lower and upper margins of the tracing. Note that not all electrographic seizures identified by the raw electroencepephlogram are equally recognizable on the CDSA or aEEG trends

technology specialists. Around-the-clock staffing may be required, EEG technologists must collaborate with critical care personnel, physicians may rely on EEG technologists to aid in frequent screening by electroencephalography, and physicians may require more remote access [88]. A standard for competency from the American Society of Electroneurodiagnostic Technologists addresses both knowledge and procedural issues as they pertain to the EEG technologist. The standard indicates that advanced training and continuing education is required to ensure that the EEG technologist "attained the advanced level of technical knowledge and skills as well as the cognitive ability necessary to interact with the critical care patient and staff to ensure a high quality ICU/cEEG recording that provides reliable information about the continuous electrophysiology of the brain" [89]. Providing EEG technologists with the opportunity to learn and develop such skills is vital to the success of CEEG monitoring in the pediatric ICU.

Pediatric ICUs are often staffed by a large number of nurses, many of whom have little experience with EEG technology. Providing nursing education via formal lectures and informal bedside training during CEEG monitoring hook-up may encourage nurses to become active participants in the CEEG monitoring process, in turn improving the data obtained from CEEG monitoring. Collaboration between nurses and EEG technologists is critical in positioning patients, performing reactivity testing, and in avoiding and trouble-shooting artifacts. Interpretation of electroencephalograms is much improved when bedside caregivers communicate information regarding patient state, medication administration, and clinical events to readers of electroencephalograms.

Although more types of providers are being asked to assist in various aspects of CEEG monitoring data acquisition in the pediatric ICU, certain advances in technology have reduced the amount of time required from each provider. CEEG monitoring in the pediatric ICU is generally performed with disc electrodes applied with collodion adhesive, decreasing the need for frequent reapplication. Although conventional electroencephalography electrodes are not compatible with CT or MRI, newly available MRI- and CT-"friendly" electrodes are reported to be safe and generate only minimal imaging artifact. Individual institutions must decide on the basis of their practice and electroencephalography staffing whether it is more time- and cost-efficient to remove and reapply electrodes when neuroimaging is needed or to employ imaging-friendly electrodes.

Generally, a full array of electroencephalography electrodes is applied according to the international 10–20 system. Reduced electrode montages may reduce workload, but at least in adults can fail to identify some seizures [90]. Video recording time-locked to the electroencephalogram allows readers to accurately identify and classify artifacts and permits detailed clinical-electrographic correlation of events, which may help bedside caregivers determine whether future events are epileptic or nonepileptic. The advent and modernization of networked CEEG monitoring systems allows data to be conveyed via a hospital network to the main neurophysiology reading system, thereby giving readers of electroencephalograms the ability to review EEG data from computers throughout the hospital or remotely.

Since performing CEEG monitoring is resource-intensive [91], institutions need to adopt clinical pathways to guide appropriate use of CEEG monitoring. Neurophysiologists generally need to review the CEEG monitoring data at least twice per day to provide the treatment team with up-to-date, actionable information. Since no guidelines or consensus statements currently exist regarding CEEG monitoring in the pediatric ICU, each institution will have to determine the most effective and efficient ways in which it can utilize its own resources.

Historical Notes and Future Directions

A routine 1-h electroencephalogram captures only about 4 % of a day's encephalographic data and unfortunately, unusual, odd, clinical "spells" and unexplained autonomic attacks rarely seem to occur during the regular daytime schedule of most electroencephalography laboratories. In the not-so-distant era of paper EEG recording, CEEG monitoring was rarely performed since it required continuous, round-the-clock presence of a technologist at the bedside to judge the quality of the tracing and to continuously replenish the paper and refill and realign the ink pens. At the end of a 24-h recording session, a small mountain of paper had to be laboriously reviewed and then stored on microfilm. The technical innovations of high-speed digital electronic data processing, high-capacity digital storage media, and the ability to seamlessly fuse digital images of the patient simultaneously with the CEEG monitoring data stream have transformed the field by allowing continuous video-EEG monitoring to be performed on a regular basis and by expediting review.

Now that the technical issues of CEEG monitoring have largely been solved, a new set of challenging questions arise. Is there agreement among different investigators about the definitions used to characterize the results of CEEG monitoring? Which patients require CEEG monitoring and for how long should CEEG monitoring be continued? How can we most efficiently and rapidly identify electrographic seizures? And most importantly, building upon the answers to all these questions, does CEEG monitoring alter management in a way that improves long-term neurodevelopmental outcome?

Answering such questions will likely require large, prospective, multicenter studies. The Critical Care EEG Monitoring Research Consortium, which contains a pediatric subgroup, has been laying the groundwork for these studies for nearly a decade. Current work includes refinement of the

terminology used in electroencephalography, which will be essential for performing studies across sites or with groups of readers of electroencephalograms, and development of a centralized database that will lay the foundation for standardized multicenter data collection.

Conclusions

Electrographic seizures are common among critically ill children with acute encephalopathy of diverse causes. Most electrographic seizures would go unnoticed even with careful clinical observation, and therefore require CEEG monitoring for their identification. There is growing evidence that electrographic seizures may contribute to brain injury and worsen outcome. CEEG monitoring is an essential tool for advancing the care of critically ill children with acute encephalopathy.

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