neurocritical care society Neurocrit Care (2011) 15:70–75
DOI 10.1007/s12028-010-9380-z

ORIGINAL ARTICLE

Impact of Continuous EEG Monitoring on Clinical Management in Critically Ill Children

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Published online: 25 May 2010

Abstract
Background Continuous EEG (cEEG) monitoring is being used with increasing frequency in critically ill patients, most often to detect non-convulsive seizures. While cEEG is non-invasive and feasible in the critical care setting, it is also expensive and labor intensive, and there has been little study of its impact on clinical care. We aimed to determine prospectively the impact of cEEG on clinical management in critically ill children.
Methods Critically ill children (non-neonates) with acute encephalopathy underwent cEEG. Study enrollment and data collection were prospective.
Results 100 children were studied. EEG monitoring led to specific clinical management changes in 59 children. These included initiating or escalating anti-seizure medications in 43 due to seizure detection, demonstrating that a specific event (subtle movement or vital sign change) was not a seizure in 21, or obtaining urgent neuroimaging that led to a clinical change in 3. In the remaining 41 children, cEEG ruled out the presence of non-convulsive seizures but did not lead to a specific change in clinical management.
Conclusions EEG monitoring led to changes in clinical management in the majority of patients, suggesting it may have an important role in management of critically ill children. Further study is needed to determine whether the management changes elicited by cEEG improve outcome.

Keywords Seizure · Status epilepticus · Pediatric · Critically Ill · Electroencephalogram · EEG monitoring

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Introduction

Continuous EEG (cEEG) monitoring is non-invasive, performed at the bedside, and permits continuous assessment of cerebral cortical function. There are a growing number of indications for cEEG in critically ill patients [1]. In many pediatric settings, the most common cEEG indication is to detect non-convulsive seizures (NCS). Pediatric age has been identified as a risk factor for NCS [2] and NCS have been reported in 16–47% of critically ill children with acute encephalopathy [3–10]. While data have not demonstrated that detection and treatment of NCS improves outcome, NCS themselves have been associated with worse outcome in adults [11–13] and neonates [14–18] and potentially injurious mechanisms have been described [19]. cEEG may also demonstrate acute changes in background features, such as focal slowing or an abrupt loss of amplitude suggesting an acutely evolving process and leading to neuroimaging or intervention. For example, cEEG has been shown to detect vasospasm in adults with subarachnoid hemorrhage [20].

While cEEG may detect NCS and other dynamic background changes, it is also expensive, time-consuming [21], and its impact on the management of critically ill children remains unclear. In adults with traumatic brain injury, cEEG data impacted clinical decisions in 90% of patients and implementation as a component of the care

protocol was associated with a significant cost savings and reduced length of stay [22]. In adults undergoing emergent monitoring, cEEG led to a change in anticonvulsant use in 52% [23]. The impact of cEEG in a pediatric population has not been previously documented. We report the impact of cEEG monitoring on clinical decisions in a prospective cohort of critically ill children.

Patients and Methods

Infants and children treated in the pediatric intensive care unit at a tertiary care referral hospital who underwent urgent cEEG between July 2008 and November 2009 were eligible for inclusion in this study. Neonates (defined as less than 1 month) were excluded. Children were prospectively and consecutively enrolled except for 6 one-week blocks when study staff was not available to obtain consent. One of the investigators approached families while their children were undergoing cEEG as part of clinical care to obtain informed consent. This study was approved by the Children's Hospital of Philadelphia Institutional Review Board.

Intensive care and neurology physicians received extensive written and lecture-based education regarding indications for urgent cEEG. The institution clinical indications for urgent cEEG were: (1) persisting altered mental status after a convulsion, (2) altered mental status without a preceding convulsion that either has an unclear etiology or is more severe than would be expected given the underlying medical condition, (3) the presence of movements or vital sign fluctuations suggestive of subtle seizures. When intensivists identified patients meeting criteria, cEEG was ordered. Clinical reading was performed by the clinical neurophysiology service, and patients were managed clinically by the PICU and Neurology Consult services.

Long-term monitoring was performed using a Grass-Telefactor (West Warwick, RI) video-EEG system. Twenty-one gold-over-silver scalp surface electrodes (Grass Technology, West Warwick, RI) were positioned according to the international 10–20 system and affixed with Collodion adhesive. EEG interpretation was performed by a pediatric clinical neurophysiologist. Electrographic seizures were defined as an abnormal paroxysmal event that was different than the background lasting longer than 10 s (or shorter if associated with a clinical change) with a temporospatial evolution in morphology, frequency, and amplitude, and with a plausible electrographic field. Non-convulsive status epilepticus (NCSE) was defined as a state of impaired consciousness with either a single 30 min electroencephalographic seizure or a series of recurrent independent electroencephalographic seizures totaling more than 30 min in any 1 h period (50% seizure burden).

This study was performed in the context of clinical neurophysiology and neurology critical care consult services. EEG technologists were available 24/7, either in-house or on-call, to initiate EEG monitoring. EEG recordings were reviewed by clinical neurophysiologists at least three times per day, with more frequent review if needed to evaluate the impact of an anticonvulsant adjustment. EEG results were conveyed by the clinical neurophysiologist to the neurology consult service, and from the consult service to the critical care service. Verbal reports were provided at least twice per day and written reports were provided at the conclusion of EEG monitoring. Physicians and nurses in the intensive care unit were asked to notify the neurophysiology service if they noted any problems with the recording, such as collector computer crash or electrode disconnection. However, they did not interpret EEG at bedside and no trends were displayed at bedside. Decisions regarding initiation or adjustment of anticonvulsants based on EEG findings were determined clinically and not dictated as part of this observational study.

Clinical and EEG data were also collected prospectively during cEEG and hospitalization. Data were acquired from the clinical chart, lab and radiology records, EEG tracings, and discussion with the involved physicians. Data collected included descriptors of the underlying medical and neurologic diagnoses, indication for EEG monitoring, EEG findings including seizure occurrence, anticonvulsant use at onset of cEEG and adjustments during cEEG, and the impact of cEEG on clinical care. The impact of cEEG findings on clinical management was rated a priori as "impacting clinical management" if cEEG findings (i) led to anti-convulsant medication initiation, adjustment, or discontinuation; (ii) indicated specific events were not seizures and thus, anti-convulsants were not indicated; or (iii) led to urgent neuroimaging.

Results

Subject and cEEG Characteristics

EEG monitoring was performed on 101 children treated in the PICU between July 2008 and November 2009. 100 consented for the study and were enrolled. The mean age was 5.7 years with a standard deviation of 6.2 years (range 44 days–21 years). Forty-eight were male. The indications for EEG monitoring were altered mental status without a prior convulsion (54), altered mental status with a prior convulsion (45), abnormal movements (8), and paroxysmal vital sign fluctuations (3). The primary conditions leading to PICU admission were hypoxic-ischemic encephalopathy (31), acute seizures with known epilepsy (24), CNS

infection (10), stroke (7), TBI (7), neurosurgical procedure (5), other non-structural (10), and other structural (6). The median duration of cEEG was 2 days (range 1–71 days). Most children were monitored for 1–2 days, children undergoing hypothermia were monitored for 3–4 days, and rare children with refractory status epilepticus were monitored for much longer. Electrographic seizures occurred in 46 children. Thirty-two had strictly NCS while 14 had a mixture of NCS and electroclinical seizures.

Impact of cEEG on Clinical Care

EEG monitoring impacted clinical management in 59% of subjects (59 of 100) (Fig. 1). The clinical management changes resulting from EEG monitoring data were anticonvulsant medication initiation (28), anticonvulsant medication escalation (15), anticonvulsant medication discontinuation (4), determining abnormal movements were not seizures (16), determining vital sign fluctuations were not seizures (5), and obtaining urgent neuroimaging that impacts clinical management (3). Seven children in whom events of interest were non-epileptic had NCS unrelated to the event of interest identified. Two children with seizures had initiation of anticonvulsant medication and urgent neuroimaging that impacted clinical management.

EEG monitoring led to urgent neuroimaging in five children and three had new changes that impacted clinical management. These included left occipital seizures which led to identification of an acute left occipital infarct, left frontal attenuation which led to identification of a left frontal subdural hemorrhage which did not expand or require surgical intervention, and multi-focal seizures which led to identification of posterior reversible leukoencephalopathy. One patient with known extensive sinovenous thrombosis and several small areas of ischemia had non-convulsive seizures and underwent urgent imaging but there was no interval change identified. One patient with an abrupt onset of mild attenuation and slowing had a normal MRI and the EEG findings were likely related to sedative medication administration.

Factors that could impact seizure occurrence and thus the utility of cEEG were further explored. Traumatic brain injury was the acute encephalopathy etiology leading to cEEG in seven children, and NCSE occurred in two of these seven. The two with NCSE had not received anticonvulsants prior to the identification of NCSE. Of the five without NCS or NCSE, two had not received any anticonvulsants while three were receiving anticonvulsants during cEEG due to initial acute symptomatic convulsive seizures. Of the 31 subjects with diffuse hypoxic-ischemic encephalopathy, 24 underwent therapeutic hypothermia during at least a portion of EEG monitoring. Seizures occurred in 12 of the 31, including 10 of the 24 (42%) who received therapeutic hypothermia and two of seven (29%) who did not undergo therapeutic hypothermia.

Discussion

This prospective study of cEEG in children who satisfied institutional criteria for EEG monitoring demonstrated that cEEG had a substantial impact on clinical care. In 59 of 100 children, cEEG findings impacted clinical care, and in some of these children there were multiple impacts (e.g. identifying NCS while also determining movements were not seizures). The most pragmatic consequence of cEEG was anti-seizure medication initiation, escalation, or discontinuation. Anti-seizure medications were initiated in 28, escalated in 15, and discontinued in 4 as a direct result of information provided by cEEG. NCS and NCSE were common, occurring in 46% of subjects, which is consistent with prior studies of cEEG in critically ill children [4–6, 8–10]. By identifying seizures, cEEG led to an anticonvulsant adjustments in 43% of children. Unnecessary anti-seizure medication administration was avoided because of cEEG data in 14 by demonstrating that their suspicious paroxysms of subtle movements or vital sign fluctuations were not epileptic in character. Commonly employed anticonvulsants can lead to adverse effects that may be particularly problematic in critically ill patients, including

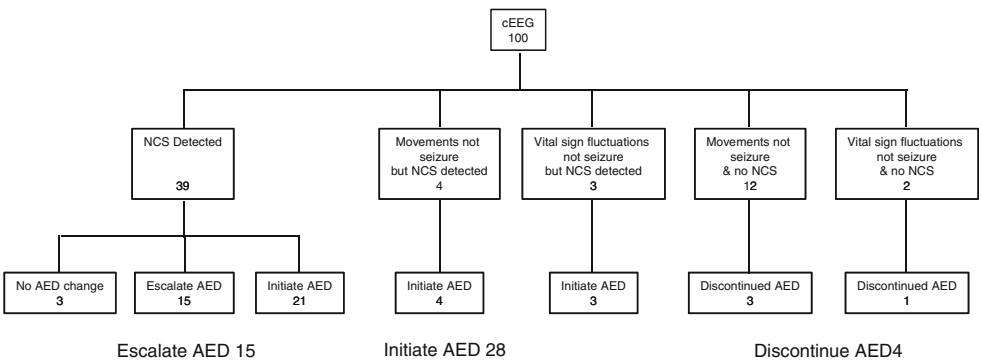

Fig. 1 Impact of cEEG on anti-seizure medication utilization

sedation, hypotension, arrhythmias, respiratory depression, and coagulopathy [24]. However, in seven children in whom events of interest were non-epileptic, NCS unrelated to the event of interest were identified. These findings are consistent with an adult study that demonstrated cEEG led to a change in anticonvulsant prescribing in 52% of all patients. Anticonvulsants were initiated in 14%, modified in 33%, and discontinued in 5% [23]. The initiation of anticonvulsants when NCS are detected is based on the presumption that NCS and NCSE are causally linked to worse outcome, and that treating NCS and NCSE may improve outcome. However, even though NCS and NCSE have been associated with worse outcome in critically ill adults [11–13] and neonates [14–18], a causal relationship has not been established.

The second consequence of cEEG was the discovery of new diagnoses in three of five children who underwent urgent neuroimaging as a result of cEEG findings. The changes in clinical management included instituting stroke care protocol, following subdural hemorrhage size, and treating moderate hypertension. The most common EEG changes that led to urgent neuroimaging were seizures and focal attenuation. This suggests that with further development, cEEG could be utilized for more than seizure detection. For example, in adults, cEEG trends may identify ischemia related to aneurismal subarachnoid hemorrhage before any clinical change is noted [20, 25] and may provide information regarding the efficacy of TPA in patients with ischemic stroke [26].

Further study is needed to determine whether cEEG data and the resultant changes in clinical management positively impact outcome. In 100 adults with traumatic brain injury, the implementation of cEEG impacted care in the majority of patients and was associated with reductions in hospital cost and length of stay. Other changes in the care protocol also occurred during that period, but the data suggest that cEEG implementation might improve care while reducing costs [22].

Seizures occurred in 39% (12 of 31) of children with diffuse hypoxic ischemic encephalopathy. In a partially overlapping cohort of 19 children, we reported that NCS are common in children undergoing therapeutic hypothermia after cardiac arrest [6]. In the current study, seizures occurred more often in children undergoing therapeutic hypothermia than those who did not undergo therapeutic hypothermia. While this could reflect a temperature impact on seizure threshold, it may reflect that children with more severe hypoxic ischemic injury were more likely to have acute symptomatic seizures and were directed to receive therapeutic hypothermia while those with less severe injury had less cause for acute symptomatic seizures and were not considered injured enough to require therapeutic hypothermia.

Electrographic seizures are reported in about 20% of adults with TBI who undergo cEEG [2, 27]. Consistent with these adult reports, in our small cohort of seven children with TBI, seizures were detected in two of seven (29%). Neither with NCS received anticonvulsants prior to cEEG, while three of the five without NCS had received anticonvulsants prior to cEEG. After TBI, prophylactic anticonvulsants may reduce the occurrence of early seizures (within 7 days) but are not associated with worse outcome [28]. However, anticonvulsants, whether administered as a prophylactic or in response to acute symptomatic seizures, could reduce or suppress electrographic seizures during the acute period, and this could reduce epileptogenic processes [29]. Further study is needed to determine whether NCS or NCSE in children with TBI are associated with worse outcome, and whether detection and management improves outcome.

This study has several limitations. First, although not evidence based, clinical practice within our institution is to initiate or adjust anticonvulsants in most patients when seizures are detected. Thus, patients with seizures have specific changes in clinical management, which then tends to justify the use of EEG monitoring. This circular reasoning demands further study to determine whether detecting and treating electrographic seizures improves outcome and to determine how aggressively NCS should be treated. Second, this study, consistent with previous pediatric studies defined electrographic seizures as lasting longer than 10 s [5, 6, 8]. However, it is unknown whether briefer evolving discharges impact outcome and warrant treatment [30]. Third, while in this study, interpretation was performed by a small group of readers and summarized by one electroencephalographer, in clinical practice variability is reported among neurophysiologists describing seizures [31] and rhythmic or periodic patterns [32] in critically ill adults. Terminology is being developed to better define NCS [33] and to describe periodic and rhythmic discharges [34], and this will be an important step in eliminating variability in future multi-center and multi-reader studies. Fourth, this study does not provide data that permits cost-effectiveness analysis. Since the impact of the cEEG-related management changes on outcome is unknown, calculating a benefit cost is not possible. Further, in many settings the true costs of EEG monitoring are likely not equivalent to hospital charges and may be difficult to calculate since they are inherently linked to the larger system costs for staff and equipment. We did not collect data regarding the exact time spent on various EEG monitoring related tasks, such as placing electrodes or reviewing EEG, but our overall impression is that each monitoring day takes about 2 h of technologist time (including electrode placement and adjustments and preliminary review) and about 30–60 min of neurophysiologist time.

Critical care physicians were not involved in EEG interpretation during this study. However, advances in quantitative EEG tools may allow bedside caregivers to identify important electrographic events, such as seizures or abrupt background changes, and this would permit real-time analysis and true monitoring [35]. Small studies have shown that with minimal training medical staff can identify electrographic seizures [36].

In conclusion, this study demonstrates that cEEG leads to management changes in the majority of children who undergo cEEG, most often as a result of seizure detection and management, but also by leading to urgent neuroimaging and by demonstrating events are not seizures so anticonvulsants and their associated potential adverse effects can be avoided. Together, these findings suggest that cEEG leads to an improved understanding of the critically ill child's overall medical condition and provides an opportunity to detect problems that can lead to important treatment decisions. Further prospective study is needed to determine whether the management changes prompted by cEEG result in improved outcome.

Acknowledgments This study is supported by NIH K12-NS049453 to Dr. Abend.

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