

ORIGINAL WORK



Continuous EEG in a Pediatric Intensive Care Unit: Adherence to Monitoring Criteria and Barriers to Adequate Implementation

Jamie Ghossein¹, Fuad Alnaji^{1,2,3}, Richard J. Webster³, Srinivas Bulusu² and Daniela Pohl^{1,2,3*} 

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Abstract

Background: Subclinical seizures are common in critically ill children and are best detected by continuous EEG (cEEG) monitoring. Timely detection of seizures requires pediatric intensive care unit (PICU) physicians to identify patients at risk of seizures and request cEEG monitoring. A recent consensus statement from the American Clinical Neurophysiology Society (ACNS) outlines the indications for cEEG monitoring in critically ill patients. However, adherence to these cEEG monitoring criteria among PICU physicians is unknown. Our project had two goals: 1. To assess adherence to cEEG monitoring indications and barriers toward their implementation; 2. To improve compliance with the ACNS cEEG monitoring criteria in our PICU.

Methods: This is a single-institution study. A total of 234 PICU admissions (183 unique patients) were studied. A 6-month retrospective chart review identified PICU patients meeting ACNS criteria for cEEG monitoring, and patients for whom monitoring was requested. This was followed by an 8-week quality improvement project. During this mentorship period, a didactic 15-min lecture and summary handouts regarding the ACNS indications for cEEG monitoring were provided to all PICU physicians. Requests for cEEG monitoring during the mentorship period were compared to baseline adherence to cEEG monitoring recommendations, and barriers toward timely cEEG monitoring were assessed.

Results: Nearly every fifth PICU patient met cEEG monitoring indications, and prevalences of patients meeting those indications were similar in the retrospective and the prospective mentorship period (18% vs. 19%). Almost all patients (98%) requiring cEEG as per ACNS criteria met the indication for monitoring already at the time of their PICU admission. During the retrospective period, 23% of patients meeting ACNS criteria had a request for cEEG monitoring, which increased to 83% during the mentorship period. The median delay to cEEG initiation was 16.7 h during the mentorship period, largely due to limited hours of EEG technician availability. Electrographic seizures were identified in 36% of patients monitored, all within the first 120 min of cEEG recording. The majority (79%) of cEEGs informed clinical management.

Conclusions: A brief teaching intervention supplemented by pictographic handouts significantly increased adherence to cEEG monitoring recommendations, and cEEGs guided clinical management. However, there were long delays to cEEG initiation. In order to promptly recognize subclinical seizures in critically ill children, we strongly advocate for a routine screening for cEEG monitoring indications as part of the PICU admission process, and a care model allowing for cEEG initiation around-the-clock.

*Correspondence: dpohl@cheo.on.ca

² Children's Hospital of Eastern Ontario, 401 Smyth Road, Ottawa, ON K1H 8L1, Canada

Full list of author information is available at the end of the article

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Introduction

Patients in the pediatric intensive care unit (PICU) are at risk for central nervous system (CNS) insults, including seizures [1, 2]. Seizures have been reported in 7–46% of comatose PICU patients [3–10], with 39–75% being exclusively subclinical [3, 4, 7, 9, 10]. Electrographic seizures impact pediatric patients in a dose-effect fashion, with higher seizure burdens predicting worse outcomes [11]. High seizure burdens, defined as a single seizure lasting at least 30 min or recurrent seizures occurring for at least 50% of the electroencephalogram (EEG) recording, are associated with increased mortality, increased length of stay in the intensive care unit (ICU), and poor neurological outcomes [1, 8, 12–15]. These findings are persistent even after adjusting for age, neurological diagnosis, illness severity, and EEG background activity [1, 13, 14]. A delayed EEG initiation and time to treatment in status epilepticus have been associated with increased mortality, highlighting the importance of prompt identification and treatment of seizures [16, 17].

The gold standard for detecting subclinical seizures is continuous EEG (cEEG) monitoring [18]. Unlike routine EEG recordings of typically around 30 min duration, cEEG monitoring is prolonged (usually ≥ 24 h) and has a much higher sensitivity for detecting subclinical seizures [19, 20]. However, restricted resources limit the access to cEEG monitoring, including insufficient machine and technologist availability [21].

Timely detection of seizures requires PICU physicians to identify patients at risk of subclinical seizures and request cEEG monitoring. A consensus statement listing indications for cEEG monitoring in critically ill children was published in 2016 by the American Clinical Neurophysiology Society (ACNS) [22]. However, adherence to these cEEG monitoring criteria among PICU physicians is unknown.

We hypothesized that PICU physicians at our center are under-monitoring patients meeting criteria for cEEG monitoring, which may contribute to under-recognition and under-treatment of seizures. Our hypothesis was based on informal observations that only one to two monitoring requests were made by our PICU per month, despite about 40 monthly patient admissions. Given the reported high prevalence of seizures in critically ill children, we predicted a gap in detection and treatment of subclinical seizures in our PICU. In order to assess cEEG monitoring rates, characterize resource

limitations, and to increase adherence to published cEEG monitoring recommendations, we conducted a quality improvement (QI) project in the PICU of our tertiary care center.

Materials and Methods

Study Design

We conducted a retrospective analysis of all children treated in our PICU during a 6-month period (January–June 2018), using our center's computerized charting database (Epic, Verona, WI). A QI project was initiated on June 24, 2018, for an 8-week period, including all patients treated by the same service (mentorship period). Patients admitted multiple times during these study periods were regarded as separate cases for the purpose of data analysis. The retrospective chart review was approved by our institution's research ethics review board, and an ethics waiver was obtained for the prospective study as it was categorized as a quality improvement project.

Patient Data

Clinical and demographic information including age, sex, seizure history, acute brain injury risk, and whether the patient met an indication for cEEG monitoring were collected for all children. The acute brain injury risk was defined in accordance with the ACNS consensus statement as the presence of at least one of the following: head trauma, CNS tumor, subarachnoid or intra-cerebral hemorrhage, ischemic stroke, CNS infection or inflammatory disease, sepsis associated encephalopathy, prolonged cardio-respiratory arrest, a neurosurgical procedure, extra-corporal membrane oxygenation or therapeutic hypothermia [22].

The clinical indications for cEEG monitoring as per ACNS were: (1) persisting altered mental status following a clinical seizure, (2) continuous intravenous antiseizure drug treatment for epilepsy, (3) altered mental status in a patient at risk of acute brain injury, (4) decline in mental status without known brain injury, (5) pharmacological paralysis in a patient with seizure risk, or (6) the presence of movements or autonomic disturbances that may represent seizures [22]. The impact of cEEG monitoring on clinical management was defined as any effect on (1) the use of antiseizure drugs (initiation, dose adjustment or discontinuation based on the results of cEEG monitoring), or (2) demonstrating that a specific event (motor or autonomic disturbance) was not a seizure. The use

of cEEG to rule out electrographic seizures as a cause of altered mental status was not included as having an impact on clinical management if it did not affect antiseizure drug use.

Retrospective Chart Review

Patient charts were individually assessed using the electronic medical health record. When screening for an indication for cEEG monitoring, this was limited to notes signed by critical care physicians. If EEG was performed, the EEG report was assessed to determine monitoring duration and findings.

Educational Intervention and cEEG Mentorship

A 15-min didactic lecture was provided to all PICU physicians (residents, fellows, and staff) during the first week of the mentorship period. The lecture included a review of clinical presentation of seizures in PICU patients, prevalence of seizures in critically ill children, and indications for monitoring with cEEG as outlined in the 2016 ACNS consensus statement. As only very limited EEG teaching is included as part of medical school, residency or PICU

fellowship, our lecture did not assume any knowledge of the topic. Attendees were asked prior to the teaching session if they were already familiar with the ACNS cEEG recommendations. This training was repeated for all new physicians rotating through the critical care service. Summary handouts of the recommendations (see Fig. 1) were attached to all mobile working stations.

Screening and Monitoring

Members of the circle of care (PICU staff, fellows, and residents) identified patients requiring cEEG monitoring in accordance with ACNS consensus statement recommendations. A medical student (JG) trained in cEEG monitoring recommendations was rounding daily under the supervision of a pediatric neurologist, and independent of the screening performed by PICU physicians, to identify patients requiring cEEG monitoring. The student relied on the discussion during rounds, as well as charted medical history, physical examination, and clinical assessment to determine if a cEEG indication was met. All cases were discussed with the pediatric neurologist to determine eligibility for cEEG monitoring.

Indications for Continuous EEG monitoring
CHEO

1. Persisting altered mental status following a clinical seizure
2. Monitor the response of refractory epilepsy to cont. IV treatment
3. Altered mental status in patient at risk of acute brain injury

4. Decline in mental status without known brain injury
5. Pharmacological paralysis in a patient with seizure risk
6. Paroxysmal seizure-like events (movements/autonomic spells)

Continuous video EEGs are indicated for patients in order to identify sub-clinical seizures. When indicated, a continuous video EEG should be ordered immediately for ≥ 24 hours of duration.

Signs of altered mental status: include but are not limited to agitation, lethargy, fixed or fluctuating neurologic deficits such as aphasia or neglect, obtundation, and coma.

1. Following a seizure: If patient is not showing improvements in alertness within **10 minutes** or has any impairment in consciousness for more than **30 minutes**.

2. Anticonvulsant efficacy monitoring: For patients with refractory status epilepticus, cEEG is used to monitor the efficacy of continuous IV antiseizure drugs such as midazolam, propofol, or pentobarbital. Refractory status epilepticus is defined as clinical or electrographic seizures that continue after initial treatment for status epilepticus, typically with a benzodiazepine and at least one more ASD.

5. Pharmacological paralysis in patient with seizure risk: includes patients on ECMO or undergoing therapeutic hypothermia.

6. Paroxysmal events: include motor movements such as subtle face or limb twitching, nystagmus, gaze deviation, eyelid fluttering, chewing, myoclonus, tremors, rigors, episodic posturing and other paroxysmal or repetitive face, limb, or trunk movements.

Patients with autonomic spells such as unexplained apnea, tachycardia, flushing, or blood pressure changes or unexplained increases in intracranial pressure, lactate or lactate/pyruvate on microdialysis should also be considered for EEG monitoring.

When unsure, please consult the neurology in-patient service.

Fig. 1 Summary card of ACNS indications for cEEG monitoring in critically ill patients. ASD antiseizure drug, cEEG continuous electroencephalogram, CHEO Children's Hospital of Eastern Ontario, Cont. continuous, ECMO extracorporeal membrane oxygenation, EEG electroencephalogram, IV Intravenous

This assessment was considered the gold standard when determining if a patient met monitoring indications.

At our institution, cEEG monitoring initiation was available between 8 a.m. and 4 p.m. Monday to Friday, and between 10:30 a.m. and 2:15 p.m. on weekends and holidays. There were four cEEG machines available for inpatient or outpatient use, none dedicated to the PICU. The neurologist on call determined the priority in allocating EEG machines when monitoring demands exceeded available resources. Requisitions were made electronically, after authorization by the on-call neurology service, as per our institution's protocol. If the neurology attending agreed with cEEG monitoring, and EEG technologists and monitors were available, patients received their monitoring as soon as the indication for monitoring was established. Any delay between ordering cEEG and initiation of monitoring was assessed through our electronic medical record system, and reasons for the delay were characterized via inquiry with the EEG technologists. If resources permitted, patients continued to be monitored for at least 24 h or as long as clinically indicated, as per published recommendations [22]. EEGs of less than 1 h in duration were not classified as cEEG monitoring and therefore not included in the study.

Statistical Analysis

Descriptive statistics was used to characterize the adherence to ACNS consensus cEEG monitoring recommendations for both the retrospective and the prospective mentorship period. A comparison of cEEG monitoring rates between the retrospective and mentorship period was made using a χ^2 test.

Results

A total of 234 admissions (183 unique patients) were studied across the retrospective period (January 1, 2018 to June 23, 2018) and mentorship period (June 24, 2018

to August 23, 2018). No significant differences in patient characteristics and cEEG monitoring requirements were noted between study periods (Table 1). During the retrospective period, 18% of patients admitted to PICU met cEEG monitoring indications, compared to 19% during the mentorship period.

Throughout the retrospective and mentorship period, all but one patient met the indication for cEEG monitoring at the time of admission (42 of 43 patients, 98%). The majority of patients met monitoring criteria outside of working hours of EEG technologists (Fig. 2).

cEEG Monitoring

None of the PICU physicians, fellows or residents were familiar with the ACNS recommendations for cEEG monitoring prior to the teaching intervention. PICU staff requested monitoring for only seven (23%) out of 31 patients who met the criteria during the retrospective period. In contrast, PICU staff requested monitoring for ten (83%) out of 12 patients who met the criteria during the mentorship period (23% vs. 83%; $p < 0.001$) (Fig. 3). Among the ten cEEGs requested,

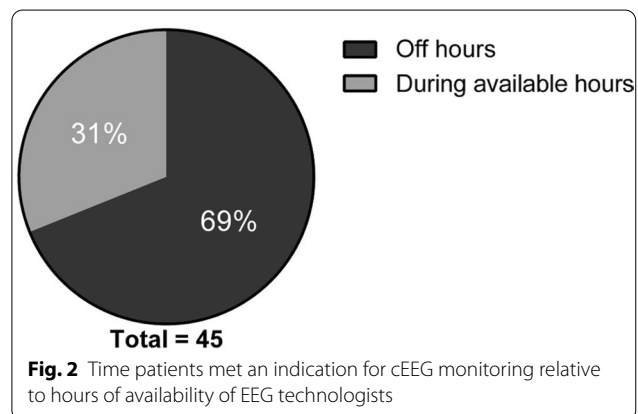
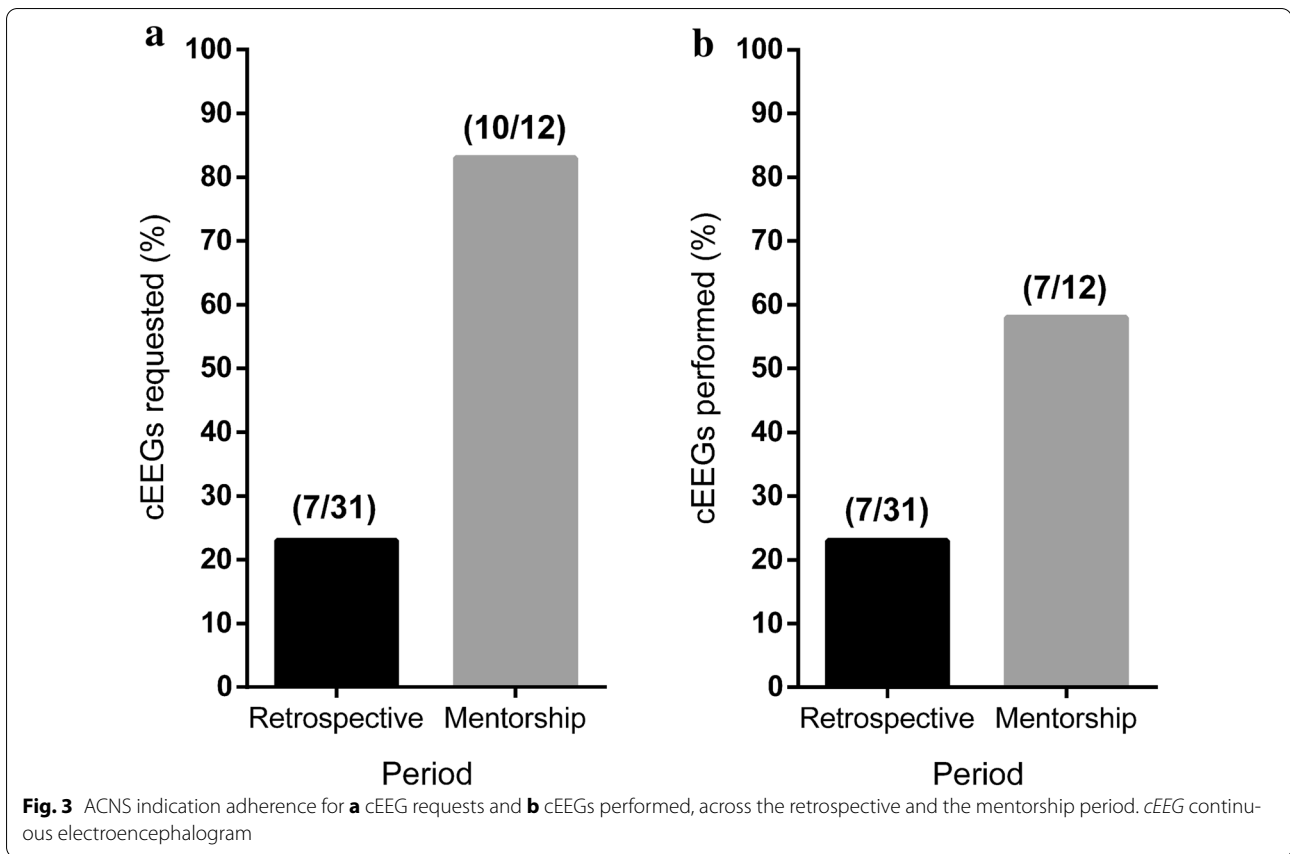


Table 1 Patient characteristics and monitoring requirements of PICU patients during the baseline and mentorship periods

Characteristics	Baseline period	Mentorship period	<i>p</i> value
Admissions	172	62	
Male gender (%)	92 (53)	31 (50)	0.6372
Median age, IQR	3.2 years, IQR 1.1–12.3 years	4.5 years, IQR 8 months–13.0 years	0.3579
Patients with acute brain injury risk (%)	24 (14)	14 (23)	0.1143
Patients with history of seizures (%)	42 (24)	10 (16)	0.1783
Patients with clinical seizure during PICU stay (%)	22 (13)	6 (10)	0.5173
Patients meeting indication for cEEG monitoring (%)	31 (18)	12 (19)	0.8165
cEEG monitoring indication met at time of admission (%)	30 (97)	12 (100)	0.5290

cEEG continuous electroencephalogram, IQR Interquartile range, PICU pediatric intensive care unit



two were not performed as the patients no longer met an indication when an EEG machine became available, and one patient received a routine EEG instead of a cEEG due to limited machine availability (Table 2). Throughout both study periods, all but one cEEG monitoring requests by PICU physicians were accepted by neurology (14 of 15 requests, 93%). Neurology did not approve of one cEEG referral as the patient's clinical status had improved by the time of neurology assessment, the patient no longer meeting indications for monitoring. A higher percentage of patients were monitored during the mentorship period compared to the retrospective period (58% vs. 23%; $p < 0.05$).

Delays to cEEG Initiation

All seven patients monitored with cEEG during the mentorship period met the indication for monitoring on admission, five out of the seven patients having met the indication outside of institutional hours of operation for cEEG initiation. A workflow limitation delayed the monitoring request for four out of seven

patients—PICU physicians were waiting until morning rounds. Once a request for monitoring was made, five out of seven patients received their cEEG within 3 h; however, there was a delay of more than 24 h for two patients due to limited machine availability (Table 3).

Impact on Clinical Management

Throughout the retrospective and mentorship periods, 11 out of 14 cEEGs (79%) affected clinical management. Five cEEGs revealed electrographic seizure activity, all identified within the first 120 min of the recording. The cEEG for one patient on continuous intravenous antiseizure drug therapy did not reveal ictal activity, which prompted medication weaning. Antiseizure drugs were stopped in two patients with presumed clinical seizures after cEEG ruled out epileptiform activity during their motor paroxysms. In three patients, cEEG assisted in ruling out seizures as an etiology of motor/autonomic spells (Table 4). In three instances where cEEG did not directly affect clinical management, cEEG ruled out subclinical seizures in patients with acute brain injury risk presenting with altered mental status.

Table 2 Patient characteristics, cEEG indications and monitoring use among children meeting ACNS cEEG monitoring criteria during the mentorship period

Patient age, gender	Indication for monitoring	cEEG requested by PICU	Received monitoring?	Reason for lack of monitoring
10 years, F	Sepsis associated encephalopathy	No	No	PICU staff did not request monitoring
10 years, F	Sepsis associated encephalopathy	No	No	PICU staff did not request monitoring
1 year, F	Monitor continuous intravenous antiseizure treatment	Yes	No	Only routine EEG as no machine available
17 years, F	Prolonged altered mental status following seizure	Yes	No	Patient no longer met indication when a machine became available
1 year, F	Prolonged altered mental status following seizure	Yes	No	Patient no longer met indication when a machine became available
1 month, M	Recurrent apneas	Yes	Yes	N/A
1 year, M	Monitor continuous intravenous antiseizure treatment	Yes	Yes	N/A
1 year, M	Altered mental status following head trauma	Yes	Yes	N/A
2 years, F	Altered mental status and CNS tumor	Yes	Yes	N/A
6 years, M	Monitor continuous intravenous antiseizure treatment	Yes	Yes	N/A
5 years, F	Episode of body stiffening and upgaze	Yes	Yes	N/A
2 years, M	Altered mental status following cardio-pulmonary arrest	Yes	Yes	N/A

cEEG continuous electroencephalogram, CNS central nervous system, EEG electroencephalogram, F female, M male, N/A not applicable, PICU pediatric intensive care unit

Discussion

Adherence to Monitoring Criteria

We identified overt under-monitoring of PICU patients at risk for subclinical seizures: At baseline, only 23% of PICU patients meeting cEEG monitoring criteria were monitored. This is similar to a prospective study in an

adult ICU patient cohort, where only 37% of patients meeting indications for routine EEG assessment received EEGs [23]. Hence, adherence to both cEEG and routine EEG monitoring recommendations among ICU physicians appears to be low, which may contribute to

Table 3 Delays in cEEG monitoring during the mentorship period

Time when cEEG monitoring indications were met	Delay between meeting indications and cEEG request (h)	Reason for delay of cEEG request	Delay between cEEG request and monitoring (h)	Reason for delay of cEEG monitoring	Total delay (h)	Seizure identified on cEEG
On admission—13:09	21.0	Awaiting neurology consult	26.5	No machine available	47.5	No
On admission—15:45	18.8	Outside of EEG hours of availability/work-flow limitation	26.3	No machine available	45.1	No
On admission—5:21	2.2	Outside of EEG hours of availability	1.8	No technologist available	4.0	No
On admission—2:27	11.1	Outside of EEG hours of availability/work-flow limitation	1.1	No technologist available	12.2	Yes
On admission—21:15	160.5	PICU attending not immediately recognizing indication	1.2	No technologist available	161.7	No
On admission—22:10	11.6	Outside of EEG hours of availability/work-flow limitation	0.9	No technologist available	12.5	Yes
On admission—23:35	14.0	Outside of EEG hours of availability/work-flow limitation	2.7	No technologist available	16.7	No
Median delay	14.0		1.8		16.7	

cEEG continuous electroencephalographic monitoring, EEG electroencephalogram, PICU pediatric intensive care unit

Table 4 cEEG impact on clinical management

Patients	How cEEG impacted clinical management
6	New ASD started or dosage optimized
2	ASD stopped
3	Avoidance of ASD treatment by ruling out seizures as an etiology for motor/autonomic paroxysms

ASD antiseizure drug, cEEG continuous electroencephalographic monitoring

under-treatment of subclinical seizures and worse outcomes for critically ill patients.

Approximately one in five children in our PICU met an indication for cEEG monitoring. To our knowledge, there are no other studies evaluating the incidence of PICU patients meeting ACNS criteria for cEEG monitoring. In view of the consistency of the rate of patients meeting criteria between our two study periods, we believe that we can generalize this finding, stating that about 20% of PICU patients will require cEEG monitoring. At our center, this would translate into at least one cEEG being performed at any given point in time. If this assumption is correct, PICUs may have to be equipped with dedicated EEG monitoring devices to avoid under-monitoring and delays in seizure treatment.

Notably, none of the PICU physicians, fellows or residents were aware of the cEEG monitoring recommendations prior to teaching interventions. Our teaching was highly effective in increasing the adherence to cEEG monitoring recommendations. During the mentorship period, 83% of patients meeting ACNS indications for cEEG monitoring were appropriately identified by PICU physicians, as opposed to only 23% at baseline. As ICU physicians are responsible for screening patients at risk for seizures, it should be incumbent on these providers to be aware of current EEG monitoring recommendations. Furthermore, we have noticed that non-physician members of the care team would often refer to the pictographic summary of cEEG recommendations during patient rounds to discuss the use of cEEG monitoring. We therefore strongly advocate that all PICU care providers, including nurses, receive teaching on cEEG monitoring recommendations.

Limited resources contributed to lower cEEG monitoring. Notably, two patients appropriately identified as requiring monitoring no longer met an indication for monitoring when an EEG machine became available (see Table 2). Additionally, one patient only received a routine EEG instead of cEEG due to limited machine availability. This is in keeping with a recent survey of 146 pediatric neurologists who are members of the Child Neurology Society, with 34% of respondents reporting barriers to performing cEEG monitoring. The three most common

barriers included inadequate availability of EEG technicians, EEG machines, and EEG readers [24]. Although resource limitations interfered with timely monitoring at our center, we were able to nearly triple monitoring rates despite unchanged resources. Thus, increasing adherence to cEEG monitoring criteria may be an effective tool to significantly improve recognition of subclinical seizures in the PICU, even if inadequate resources may still interfere with achieving timely cEEG monitoring.

cEEG Monitoring

For the vast majority (98%) of our patients requiring cEEG monitoring, indications were already met at the time of their PICU admission. We therefore strongly advocate for a routine screening for an indication for cEEG monitoring as part of the admission process of critically ill children. cEEG monitoring criteria should be included in the PICU admission checklist, similar to other routine investigations such as chest X-ray and ECG.

Thirty-six percent of our EEG-monitored PICU patients had electrographic seizures (five out of 14 patients monitored). We are not aware of other studies describing the seizure detection rate among children meeting the new ACNS monitoring criteria. In view of the fact that more than one out of three patients meeting ACNS criteria had subclinical seizures, the recommendations appear to adequately identify PICU patients at very high risk of seizures. However, for assessing the sensitivity of the recommendations, and the true incidence of subclinical seizures among PICU patients, systematic cEEG screening of all patients would be required in future resource-intensive studies.

Of note, all seizures were detected within the first 120 min of cEEG recording, and three of the five seizures even within the first 30 min of EEG recording (60%). Although limited by a small sample size, this is consistent with studies demonstrating that traditional 30–60 min EEG recordings identify nonconvulsive seizures in 52–74% of patients in whom seizures are eventually recorded [9, 19, 25]. In accordance with our study, it has been reported that in patients without epileptiform activity during the first 4 h of monitoring, no seizures were subsequently detected in a study of 242 adult patients undergoing cEEG monitoring [25]. These findings suggest that the first 4 h of cEEG monitoring are critical in determining which patients may require prolonged monitoring, which may assist in managing EEG machine use in resource-restricted centers.

We were able to demonstrate that 79% of cEEGs informed clinical management, whether through direct effect on pharmacotherapy or in determining the etiology of motor/autonomic paroxysms. These findings are consistent with a prospective study of 100 children undergoing

cEEG monitoring, where 57% of cEEGs affected clinical management [26]. Thus, cEEG is a highly effective tool in guiding treatment when performed in the pediatric critical care setting, especially in informing pharmacotherapy.

Barriers

Our institutional limitation of cEEG initiation between 8 a.m. and 4 p.m. has contributed to significant delays in cEEG monitoring for our PICU patients. Unsurprisingly, 69% of patients throughout both study periods met an indication for monitoring after hours. In a 2011 survey of 58 North American PICUs, 21% of centers noted that technologists were not always available, and 51% of centers reported that technologists were always available but sometimes only by call-back [21].

The requirement for the neurology in-patient service to approve cEEG monitoring requests at our center also contributed to a delay in monitoring in the form of a workflow limitation. Based on our observations, PICU physicians typically awaited patient rounding in the morning to make the requisition with neurology instead of requesting a cEEG as soon as the monitoring indication was established. The median delay before PICU physicians placed a cEEG request was 14 h. As 14 out of 15 monitoring requests (93%) throughout both study periods were accepted by neurology, we advocate for enabling trained PICU physicians to order cEEG monitoring without prior approval by neurologists, with the goal of minimizing monitoring delays. PICU physicians should ideally request monitoring as soon as an indication for monitoring is established.

We believe the gold standard for cEEG monitoring is a care model allowing for cEEG initiation and interpretation around-the-clock. In order to initiate cEEG recordings after hours, some centers train nurses to apply electrode templates or EEG caps [27]. The general trend to increase cEEG monitoring may burden EEG readers. In most centers, EEG readers are facing competing in- and outpatient demands potentially interfering with a timely interpretation of cEEG recordings.

Quantitative EEG allows for interpretation of large volumes of EEG data produced by cEEG through software tools [28]. Although quantitative EEG analysis allows for rapid bedside EEG activity interpretation by PICU staff, the sensitivity and specificity for detection of seizures is poor when compared to the interpretation of raw cEEG recordings [28–33]. In order to address the larger burden of EEGs requiring interpretation by regular EEG readers, cEEG screening of raw EEG recordings for seizure detection might be a clinically relevant skill for bedside staff, including PICU attendings, fellows, residents, and nursing staff. The combination between quantitative and raw EEG analysis in a multifaceted screening process may

increase efficiency and facilitate treatment decisions by PICU physicians. Whether non-expert EEG readers can be trained in basic bedside EEG interpretation requires further investigation.

There are limited studies in children on the delay of treatment of subclinical seizures and its effect on patient outcomes. Many studies have established an association of higher seizure burdens with higher mortality and worse neurological outcome in children, after adjustment for illness severity and diagnosis [1, 14, 15, 34]. Notably, in a retrospective study of 237 children with status epilepticus, seizure duration of 210 min as compared to 30 min was associated with worse outcome defined as mortality, development of new neurological deficits or development of epilepsy [34]. Treatment delay of more than 10 min in convulsive status epilepticus was associated with increased mortality, as reported in a study of 218 children with refractory status epilepticus [16]. Time to EEG has been independently associated with increased mortality in critically ill children [17]. These and other similar findings are reflected in the most recent Neurocritical Care Society guideline that cEEG should be used to identify nonconvulsive status epilepticus in comatose patients, and that treatment should be initiated rapidly until both clinical and electrographic seizures cease [35].

Limitations

This is a single center study limited by a modest sample size of 176 patients. As cEEG initiation protocols and access to resources may differ at other pediatric centers, the external validity of our findings may be limited. Our experiences with cEEG monitoring may not be applicable to larger centers with additional resources. Although cEEG requests increased following teaching interventions, we did not assess the long-term retention of good monitoring practices learnt from mentorship.

Conclusion

Our study demonstrated overt under-monitoring of patients at risk of subclinical seizures, which significantly improved through teaching interventions. In order to promptly recognize subclinical seizures in the PICU, a care model which allows for cEEG initiation outside of regular hours should be considered. Future studies may evaluate cEEG initiation by PICU nurses and bedside interpretation by non-neurologists, allowing for prompt recognition and treatment of seizures, thereby improving patient outcomes.

Author details

¹ Faculty of Medicine, University of Ottawa, Ottawa, ON, Canada. ² Children's Hospital of Eastern Ontario, 401 Smyth Road, Ottawa, ON K1H 8L1, Canada.

³ CHEO Research Institute, 401 Smyth Road, Ottawa, ON K1H 8L1, Canada.

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Authors Contributions

JG contributed to data acquisition, analysis, and interpretation. RJW and DP contributed to data interpretation. All authors contributed to the conception, drafting, critical revision and final approval of the manuscript.

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This study is not sponsored or funded.

Compliance with Ethical Standards

Conflict of interest

None of the authors have any conflict of interest to disclose.

Ethical Approval

The study complies with all applicable ethical guidelines. The retrospective chart review was approved by our institution's research ethics review board, and an ethics waiver was obtained for the prospective study as it was categorized as a quality improvement project. The study complies with the SQUIRE checklist for quality improvement studies.

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