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EEG Monitoring in Critically Ill Children: Indications and Strategies

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Abstract

Continuous electroencephalographic monitoring often detects non-convulsive seizures in critically ill children, but is resource intense and has not been shown to improve outcome. As institutions develop clinical pathways for monitoring, it is important to consider how seemingly minor variations may have a substantial impact on resource utilization and cost. We performed a one month prospective observational study in which each patient in a 45-bed pediatric intensive care unit was screened for potential monitoring indications. 247 patients were screened. Minor differences in monitoring indications would have a substantial impact on resource utilization. We then calculated the number of monitoring days that would be required each month based on two strategies that differed in monitoring duration. The *prolonged-targeted* and *brief-targeted strategies* would have required 106 and 33 monitoring days, respectively. Based on published non-convulsive seizure occurrence data, these strategies would detect 0.14, and 0.43 patients with seizures per monitoring day performed, respectively. A brief-targeted strategy provides a high yield for non-convulsive seizure identification, but would fail to diagnose some patients with seizures.

Keywords

EEG Monitoring; Non-Convulsive Seizure; Pediatric

Introduction

Continuous electroencephalographic (EEG) monitoring is increasingly utilized in critical care settings to identify and manage non-convulsive seizures and non-convulsive status epilepticus,[1, 2] which have been reported in 7-47% of monitored children.[3-14] Such a large range may be explained by varying monitoring indications and duration. A study in

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which only half of subjects had an acute neurologic disorder reported seizures in 7%,[12] while studies with a higher proportion of subjects with acute neurologic disorders reported seizures in 38-47%.[3, 6, 13, 14] Studies describe that 80-87% of seizures are identified in the first 24 hours of monitoring. [3, 6, 12, 13] Some specific risk factors have been identified including younger age,[3, 13, 15] post-convulsive status epilepticus[13] or seizures,[14] acute structural brain injury,[14] traumatic brain injury,[13] lack of EEG reactivity,[6] and the presence of epileptiform discharges.[6, 13, 14]

Non-convulsive seizures or status epilepticus have been associated with worse outcome in critically ill adults and neonates.[16-21] Detrimental changes in cerebral physiology and regional atrophy have been described in adults with traumatic brain injury experiencing non-convulsive seizures.[22, 23] However, studies have not yet explored whether seizure identification and management improves outcome. EEG monitoring requires an extensive technical infrastructure and also the time and expertise of EEG technologists and clinical neurophysiologists. The costs are considerable and in the absence of clear data that these efforts improve outcome, strategies are needed to make the best use of limited healthcare resources. As institutions develop EEG monitoring pathways, it is important to consider how variations in EEG monitoring indications and duration impact patient care and resource utilization. Understanding this variability will help neurologists develop appropriate institutional infrastructures, allocate human resources, and formulate feasible institutional pathways for EEG monitoring.

We prospectively evaluated the number of critically ill children in a tertiary care pediatric intensive care unit who would require EEG monitoring each day based on specific *a priori* indications. Subsequently, we used these data to compare two different monitoring strategies.

Study Design and Methods

All infants and children (1 month-18 years) being treated in the 45-bed pediatric intensive care unit of The Children's Hospital of Philadelphia over a one month period during the Summer of 2010 were prospectively screened for specific EEG monitoring indications. Demographic information was obtained, including Pediatric Risk of Mortality III scores[24] at 12 hours. Critical care physicians and nurses completed screening data sheets immediately after rounding on each patient. This study did not involve any actual EEG monitoring, although patients underwent monitoring if clinically indicated. This study was approved by The Children's Hospital of Philadelphia Institutional Review Board.

A priori potential EEG monitoring indications were: (1) altered mental status (compared to baseline mental status for the individual), (2) acute primary neurologic disorder, (3) acute convulsive seizure, (4) episodic abnormal eye movements, (5) episodic abnormal vital sign fluctuations, (6) episodic abnormal movements, (7) prior epilepsy diagnosis, and (8) receiving an anticonvulsant. Although epidemiologic data regarding non-convulsive seizure occurrence is not available for many of these indications, they are often considered potential indications for EEG monitoring.[25] For each indication we report the percentage of patients who met each indication on any day while in the intensive care unit (period prevalence). Patients could have multiple indications.

Altered mental status was defined as a Glasgow Coma Scale of less than 12 and did not require that the patient be comatose. Since some patients had chronic static encephalopathy, altered mental status was considered a reduction in mental status from an individual's baseline. *Acute primary neurologic disorder* refers to acute disorders primarily involving the central nervous system including traumatic brain injury, stroke, encephalitis, prolonged seizures or status epilepticus, status-post a neurosurgical procedure, and shunt dysfunction

or infection. Since patients were being screened each day they were in the pediatric intensive care unit, if they met a criterion on consecutive days or if they improved (ie. did not meet a given criterion) and then worsened (ie. met a given criterion again), each of these days was considered a separate instance of meeting the criterion.

Utilization data are presented for two monitoring strategies, which are defined by duration. A *prolonged-targeted monitoring strategy* is defined as monitoring children with an acute primary neurologic disorder on all days with altered mental status. Prospective study has shown that 46% of these children have non-convulsive seizures (including non-convulsive status epilepticus), with 100% detected within the first 72 hours.[3] In a *brief-targeted monitoring strategy*, children with an acute primary neurologic disorder and altered mental status undergo EEG monitoring for the first 24 hours of altered mental status. Prospective study has shown that of children with non-convulsive seizures (and no convulsive seizures identified by EEG monitoring), 94% are detected on the first day of monitoring.[3]

The monitoring strategies are evaluated using two measures. *EEG monitoring yield* is the number of non-convulsive seizure patients diagnosed per day of EEG monitoring - a measure of resource utilization efficiency. Higher values indicate more efficient use, and a value of one indicates that every EEG day identifies a patient with seizures. *Non-convulsive seizure yield* is the percentage of patients with seizures diagnosed by a monitoring strategy - a measure of how reliably patients with non-convulsive seizures would be identified. The values listed in Table 2 columns B and G have been published.[3]

Results

Subjects

A total of 247 patients received care in the pediatric intensive care unit, totaling 833 patient-days. There were 147 males and 89 females. The mean age was 7.3 years (standard deviation 7.1 years). Nine percent of subjects were intubated. Pediatric Risk of Mortality Scores III were calculable for 73% of subjects and the mean score was 5 (standard deviation 6.7).

EEG Monitoring Requirements Based on Indications

Table 1 lists the percentage of patients admitted during the study period requiring EEG monitoring based on specified indications. Data regarding several combined indications are also shown. For example, 68 subjects (27%) had altered mental status, 80 subjects (32%) had a primary acute neurologic disorder, and 33 subjects (13%) had altered mental status and an acute primary neurologic disorder.

EEG Monitoring Yield by Monitoring Strategy

Table 2 shows the number of EEG monitoring days and yield for each strategy based on the Table 1 category altered mental status & acute primary neurologic disorder. This indication category was used since prospective data regarding seizure incidence is available.[3] The numbers of children with non-convulsive seizures that would be identified during the month are estimated, allowing calculation of the EEG monitoring yield for each strategy. For example, the *brief-targeted monitoring strategy* monitors patients with altered mental status and an acute primary neurologic problem for one day. Thirty-three patients met these criteria during the screening month. If 43% have seizures within 24 hours,[3] then 14.2 patients with non-convulsive seizures would be identified per month by 33 days of EEG monitoring. Thus, 0.43 patients with non-convulsive seizures would be identified per day of monitoring. As shown in the last column (Non-Convulsive Seizure Yield), approximately 94% of

subjects with non-convulsive seizures would be identified during the single day of monitoring.[3]

Discussion

Non-convulsive are common in critically ill children and identification requires EEG monitoring.[3, 6, 13, 14] Monitoring strategies that vary in indication and duration have a substantial impact on EEG monitoring yield (resource utilization) and some impact on non-convulsive seizure yield (patient identification). If a hospital has limited monitoring resources, then a strategy for optimal utilization is needed, and the impact of the strategy on patient care should be estimated. The current study, together with data addressing time to first non-convulsive seizure,[3] indicates that if a *brief-targeted monitoring* strategy is utilized, then the EEG monitoring yield (number of non-convulsive seizure patients detected per monitoring day) is 0.43 and the non-convulsive seizure yield is 94%. With the *prolonged-targeted strategy*, the EEG monitoring yield decreases to 0.14 non-convulsive seizure patients per EEG monitoring day, but this tripling of resource utilization improves the non-convulsive seizure yield to 100%.

A *brief-broad monitoring strategy* might also be considered. This refers to monitoring all critically ill children who are comatose or have altered mental status for one day, whether or not they have an acute primary neurologic disorder. A monitoring study directed at children with *altered mental status* without an acute primary neurologic disorder (toxic-metabolic encephalopathy) is not available to our knowledge. However, one prospective study performed monitoring for a median of 20 hours in 100 consecutive critically ill *comatose* (Glasgow Coma Scale score < 8) children, about half of whom had a primary neurologic disorder, and identified non-convulsive seizures in 7%, all of whom had prior epilepsy diagnoses.[12] In our prior cohort, the degree of altered mental status (comatose versus altered but not comatose) did not impact non-convulsive seizures occurrence.[3] In this study, if the 68 subjects with altered mental status (with or without an acute primary neurologic disorder) underwent one day of monitoring and 7% had non-convulsive seizures, [12] then 4.8 children with non-convulsive seizures would be identified, leading to an EEG monitoring yield of 0.07. This low EEG monitoring yield is consistent with a prior conclusion that EEG monitoring of all comatose children in a pediatric intensive care unit may not be justified.[12] Similarly, a *high-risk monitoring strategy* could be considered based on identified risk factors such as younger age (under one year)[3, 13] and acute structural brain disorders.[14] These studies indicate about 60% of these children would experience non-convulsive seizures with one day of EEG monitoring. There were 13 of these subjects in our cohort. Thus, eight with non-convulsive seizures would be identified, yielding an EEG monitoring yield of 0.62.

Converting yield numbers to dollar values is illustrative but complex. EEG monitoring charges are generally confidential, include both technical and professional components, and vary by institution. Further, discrepancies usually exist between charges and payments. Assuming that payment for one day of EEG monitoring was \$1000, using the *brief-targeted monitoring* strategy (EEG monitoring yield of 0.43), 2.3 days of monitoring are required to identify one patient with non-convulsive seizures, and this would cost \$2320. Similarly, identifying one patient with non-convulsive seizures using the *high-risk, prolonged-targeted*, and *brief-broad monitoring strategies* would cost \$1612, \$7143 and \$14,285, respectively. These values have limited utility since they are calculated based on limited non-convulsive seizure epidemiologic data and an assumed EEG monitoring payment. However, they illustrate the substantial cost differences that may result from seemingly small variations in EEG monitoring use and motivate further epidemiologic study. Performing cost effectiveness analyses will require data addressing the impact of non-

convulsive seizures on quality of life to develop the requisite quality-adjusted- life-year calculations.

While the categories in Table 1 are all potential indications for EEG monitoring in some clinical settings, epidemiologic data are only available for the categories of altered mental status and acute primary neurologic disorder[3] and *coma*. [12] The period prevalence data for the other categories give a sense of the frequency with which the other indications can be encountered; determining the incidence of non-convulsive seizures in these categories would be of interest.

Studies in critically ill adults also report non-convulsive seizures, although often with a lower incidence than in pediatric studies. One study that included adults and children identified age younger than 18 years as a risk factor for non-convulsive seizures.[15] Some studies in adults have reported an association between non-convulsive seizures and worse outcome.[16-18, 26] One study of adults with traumatic brain injury reported that EEG monitoring accounted for 1% of overall hospital costs. Further, when comparing time periods before and after EEG monitoring implementation, overall costs and length of stay declined and short-term outcome improved during the period with EEG monitoring.[27]

This study has limitations. First, our pediatric intensive care unit studied is separate from the cardiac intensive care unit and this probably reduced the number of patients meeting criteria for EEG monitoring since many children with congenital heart disease are at risk for neurologic complications including non-convulsive seizures.[28-31] Second, the study was conducted during 28 summer days, and diagnosis prevalence might vary by season. Third, this study was conducted in a free-standing tertiary care children's hospital, and the pediatric intensive care unit population studied may not be representative of all pediatric intensive care units. The current work emphasizes terminology and a framework for deciding on a monitoring strategy rather than recommending one strategy for all pediatric intensive care units. Ideally, each pediatric intensive care unit would determine its own patient profile, decide on a monitoring strategy that optimizes resource utilization and patient care, and then allocate adequate resources. Fourth, the data used to calculate the EEG monitoring and non-convulsive seizure yields were derived from one study which was performed in a single pediatric intensive care unit, included only 100 subjects, and performed monitoring for a limited duration.[3] Larger epidemiologic studies are needed.

The monitoring strategy calculations consider all non-convulsive seizures to be equivalent and clinically important to identify. However, improved non-convulsive seizure classification might reveal that only some non-convulsive seizure subtypes impact outcome. Further, identifying non-convulsive seizures is of value only if they are causally associated with worse outcome. An understanding of the clinical consequences of these seizures will help balance efficient resource utilization and optimal patient care, and this is needed before EEG monitoring becomes an entrenched monitoring modality.

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Table 1

Percentage of patients (N=247) that would require EEG monitoring based on indication.

	EEG Monitoring Indication	% (N) patients meeting indication
Single EEG Monitoring Indications	Altered Mental Status	27.5% (68)
	Acute Primary Neurologic Disorder	32.4% (80)
	Acute Seizure	8.1% (20)
	Episodic Abnormal Eye Movement	6.9 % (17)
	Episodic Vital Sign Fluctuations	6.5% (16)
	Episodic Abnormal Movement	6.9 % (17)
	Prior Epilepsy Diagnosis	14.6% (36)
	On Anticonvulsant	20.6% (51)
Combined EEG Monitoring Indications	Altered Mental Status & Acute Primary Neurologic Disorder	13.4% (33)
	Altered Mental Status & Acute Seizure	4% (10)
	Altered Mental Status & Acute Primary Neurologic Disorder & Acute Seizure	4% (10)
	Received Paralytic in the last 24 hours & Acute Primary Neurologic Disorder	7.7% (19)
	Prior Epilepsy Diagnosis & Altered Mental Status	5.3% (13)

Table 2
Continuous EEG monitoring yield and non-convulsive seizure yield by monitoring strategy.

Monitoring Strategy	A Number of patients meeting EEG monitoring indication during screening month	B % with non-convulsive seizures reported in literature	C Average number of patients with non-convulsive seizures C=B% of A	D Average EEG monitoring duration (days)	E Average EEG monitoring number of days E=A×D	F EEG Monitoring Yield F=C/E	G Non-Convulsive Seizure Yield ^b
Prolonged-Targeted	33	46% ^c	15.2	3.2 ^d	106	0.14	100% ^c
Brief-Targeted	33	43% ^c	14.2	1 ^e	33	0.43	94% ^c

^a EEG Monitoring Yield = Non-convulsive seizure patients detected per EEG monitoring day.

^b Non-convulsive seizure Yield = estimate of patients with non-convulsive seizures who would have non-convulsive seizures identified using this strategy based on published literature.

^c Reference 3. 46% of children undergoing EEG monitoring have non-convulsive seizures, and 100% are detected with 72 hours of monitoring. 43% of children undergoing EEG monitoring have non-convulsive seizures detected in the first 24 hours of monitoring, indicating 94% of children with non-convulsive seizures could be identified with 24 hours of monitoring.

^d Average duration of altered mental status from screening month data.

^e By definition, EEG monitoring duration is one day for the brief-targeted strategy.