

Digital Video-Electroencephalographic Monitoring in the Neurological-Neurosurgical Intensive Care Unit

Clinical Features and Outcome

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Background: Prolonged electroencephalographic (EEG) recordings in the neurological-neurosurgical intensive care unit (NICU) may be performed in patients with status epilepticus, repetitive seizure activity, or an encephalopathy with or without seizures. The electroclinical correlation and neurological outcome of patients undergoing digital video-EEG monitoring (DVEEG) in the NICU has not been determined.

Objectives: To evaluate the clinical utility and prognostic importance of the DVEEG in the NICU.

Methods: We retrospectively evaluated 105 patients who underwent DVEEG in the NICU at the Mayo Clinic, Rochester, Minn, between January 1, 1994, and July 31, 2001. All patients had a routine EEG recording performed prior to DVEEG.

Results: The mean age of the patients at the time of the DVEEG was 54 years (age range, 16-88 years). The mean duration of the DVEEG was 2.9 days (range, 1-17 days). Forty-four patients (42%) had a severe encephalopathy (Glasgow Coma Scale score, <8) at the time of the DVEEG. Forty-five patients (42.8%) had general-

ized convulsive status epilepticus, 19 patients (18.1%) had nonconvulsive status epilepticus, and 7 patients (6.7%) had epilepsy partialis continua. The mean duration of follow-up was 7 months (range, 1-54 months). The outcome in 84 patients included death in 38 patients, severe neurological deficits, that is, bed bound and needs support for activities of daily living, in 6 patients, and a vegetative state in 3 patients. Fifteen individuals had no neurological impairment during follow-up. Refractory status epilepticus ($P<.003$), hypoxic-ischemic encephalopathy ($P<.004$), and multiple cerebral infarcts ($P<.003$) were the factors associated with increased mortality in univariate analysis. With multivariate logistic regression analysis only the presence of multiple strokes ($P<.03$; odds ratio, 5.62) was predictive of mortality.

Conclusions: Continuous EEG monitoring is essential in the diagnosis and treatment of refractory status epilepticus or an encephalopathy with seizures in the NICU. A minority of these patients, however, experienced a favorable neurological outcome.

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LONG-TERM ELECTROENCEPHALOGRAPHIC (EEG) monitoring is an important diagnostic technique used in selected patients in the neurological-neurosurgical intensive care unit (NICU).¹⁻⁴ The potential clinical applications of prolonged EEG recordings in the NICU include the evaluation of patients with an encephalopathy, status epilepticus, or repetitive seizure activity.¹⁻⁴ These electrophysiologic studies provide a continuous monitoring of cerebral function and are a reliable indicator of electrographic seizure activity.³ The feasibility and diagnostic yield of long-term EEG monitoring in patients with neurological disorders requiring critical care has previously been reported.^{1,3,4} Digital video-EEG monitoring (DVEEG) is a recent innovation that

permits online spike and seizure detection, digital filtering, montage reformatting, data reduction, and off-line seizure analysis.^{5,6} The clinical utility and prognostic importance of the DVEEG in the NICU are unknown. The rationale for the present study is to assess the diagnostic yield and predictive value of the DVEEG in patients requiring long-term EEG recordings.

METHODS

PATIENT POPULATION

We retrospectively studied 612 consecutive patients who underwent DVEEG monitoring in the NICU at the Mayo Clinic, Rochester, Minn, between January 1, 1994, and July 31, 2001. The individuals were identified using the epilepsy-

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EEG-monitoring database at this institution. Patients aged 16 years and younger and individuals undergoing extracranial or intracranial EEG monitoring for evaluation of candidacy for surgical treatment of intractable epilepsy were excluded from the present series. The patients' medical records, hospital charts, and correspondence were reviewed after appropriate approval by the institutional review board of the Mayo Foundation. A routine scalp-recorded EEG recording was performed immediately prior to DVEEG for a minimum period of 30 minutes. Activation procedures, including eye opening and eye closure, hyperventilation, and photic stimulation, were used if appropriate.

INDICATIONS FOR DVEEG MONITORING

The indication for DVEEG in these patients was separated into 5 groups: generalized convulsive status epilepticus (GCSE), encephalopathy with or without seizures, acute repetitive seizures or recurrent seizures, epilepsy partialis continua, and spell classification (**Table 1**). All of the patients in the present series were determined to require care in the NICU because of their underlying acute neurological disorder or need for immediate postoperative care after a neurosurgical procedure. All of the patients with status epilepticus or an encephalopathy requiring NICU care were intubated for mechanical ventilation, airway protection, or both. The diagnosis of GCSE used for this study was proposed by the Epilepsy Foundation of America's Working Group on Status Epilepticus.⁷ Patients with GCSE were admitted to the NICU if the seizures were refractory to intravenous benzodiazepine drugs, fosphenytoin sodium, or both. Patients who remained unresponsive subsequent to treatment of GCSE or who experienced an adverse event related to seizure activity or medical treatment (eg, hypotension) were also evaluated in the NICU. Digital video-EEG monitoring was invariably performed in patients with refractory status epilepticus who were receiving continuous infusions of midazolam hydrochloride, propofol, or pentobarbital. The clinical response to treatment and the continuous EEG monitoring pattern were used to determine the treatment strategy in patients who had seizures. Criteria for electrographic seizure, nonconvulsive status epilepticus (NCSE), and epilepsy partialis continua were adapted from previous descriptions.⁷⁻¹²

EEG METHODS

All patients had computer-assisted video-EEG monitoring performed with automatic seizure recognition and off-line seizure analysis.^{6,13-15} A modified "10-20 System" (the modified combinatorial nomenclature) was used as approved by the American Electroencephalographic Society in 1991.¹³ An extension of the 10-20 System was used to designate the 10% electrode positions.¹³ Positions 10% inferior to the standard frontotemporal electrodes were designated as F9/F10, T9/T10, and P9/P10.¹³ Intracranial and sphenoidal electrodes were not used. The DVEEG recordings used similar montages in all patients for 23 channels of EEG activity with 1 channel for electrocardiographic activity. One system was used for all of the DVEEG studies (Network Concepts Inc, Middleton, Wis). The patients were monitored continuously at all times by a trained video-EEG monitoring technician using closed-circuit television who was in contact with the nursing personnel and physicians in the NICU.

NEUROLOGICAL OUTCOME

The neurological outcome was determined in 84 (80%) of the 105 patients following completion of the DVEEG. The outcome could not be assessed in 21 patients who were dismissed from the NICU and were not subsequently followed up at this institution. The neurological outcomes were divided into 6

Table 1. Indications for Digital Video-Electroencephalographic Monitoring

Indication	No. (%) of Patients
Generalized convulsive status epilepticus	45 (42.8)
Encephalopathy with or without seizures	37 (35.2)
Acute repetitive or recurrent seizures	12 (11.4)
Epilepsia partialis continua	7 (6.7)
Behavioral spell classification	4 (3.8)

groups using the Glasgow Outcome Scale: good recovery (able to return to work or school), moderate disability (able to live independently; unable to return to work or school), severe disability (able to follow commands; unable to live independently), vegetative state (unable to interact with environment; unresponsive), and death.^{16,17} The patients with a good recovery for purposes of this study were further separated into healthy (no signs or symptoms of neurological disease) and mild disability (able to return to work or school with evidence of neurological signs and symptoms).

STATISTICAL ANALYSIS

We used the *Epi Info* statistical program (version 6 [2000]; Centers for Disease Control and Prevention, Atlanta, Ga) for the analysis of data. The statistical methods included *t*, χ^2 , and Fisher exact tests for assessing the significance for different variables with outcome. Multivariate logistic regression was performed to determine the relative weighting of each of the variables with mortality.

RESULTS

One hundred five patients (58 men [55.2%] and 47 women [44.7%]) met the inclusion criteria and were evaluated in the present study. The cohort's mean age was 54 years (age range, 16-88 years). Seventy-five patients (71.4%) were admitted to the neurology service and 30 patients (28.5%) were under the care of neurosurgery. The mean duration of DVEEG monitoring was 2.9 days (range, 1-17 days). The indications for DVEEG monitoring are summarized in Table 1. The most common indications for DVEEG monitoring were status epilepticus or an acute encephalopathy (Table 1). The neurological history and electroclinical correlation supported the diagnosis of GCSE in 45 patients (42.8%), NCSE in 19 patients (18.1%), and epilepsy partialis continua in 7 patients (6.7%). The age distribution of the patients, seizure type(s), and the duration of illness are given in **Table 2**. Most of the individuals had an acute neurological disorder that was present for several days prior to DVEEG monitoring (Table 2). **Table 3** lists the potential causes and comorbid conditions in these patients.

NEUROLOGICAL FINDINGS

Ninety-nine patients (94.3%) had an abnormal neurological examination. A hemiparesis or quadriplegia was observed in 29 patients (27.6%) and 10 patients (9.5%), respectively. Twelve patients (11.4%) had a primary neurodegenerative disorder with significant cognitive impairment. Seventeen patients (16.1%) had a Glasgow Coma Scale (GCS) score of 3. The GCS scores ranged be-

Table 2. Age Distribution, Seizures Type(s), and Duration of Illness

Clinical Factor	No. (%) of Patients
Age distribution, y*	
16-29	22 (20.9)
30-49	22 (20.9)
50-69	37 (35.2)
70-89	24 (22.8)
Seizure type(s)†	
Simple partial	38 (36.1)
Generalized tonic-clonic	43 (40.9)
Complex partial	23 (21.9)
Secondary generalized	11 (10.4)
Myoclonic	2 (1.9)
Duration of illness‡	
<30 min	1 (0.9)
30 min to 1 h	6 (5.7)
1-24 h	11 (10.4)
1-7 d	53 (50.4)
>7 d	15 (14.2)

*Age at time of digital video-electroencephalographic monitoring.

†Classification of seizure activity in the neurological-neurosurgical intensive care unit.

‡Duration of symptomatic illness prior to digital video-electroencephalographic monitoring.

Table 3. Symptomatic Causes or Coexistent Morbidity

Cause	No. (%) of Patients*
Central nervous system infection	20 (19.0)
Viral encephalitis	14
Meningitis	5
Creutzfeldt-Jakob disease	1
Degenerative diseases	18 (17.1)
Dementia	5
Parkinson plus syndrome	3
Static encephalopathy	3
Mitochondrial disease	2
Progressive myoclonus epilepsy	2
Storage disease	1
Normal pressure hydrocephalus	1
Charcot-Marie-Tooth disease	1
Brain tumor	16 (15.2)
Primary	15
Metastatic	1
Vascular	29 (27.6)
Cerebral infarction(s)	12
Subdural hematoma	10
Intracerebral hemorrhage	7
Others	22 (20.9)
Metabolic†	14
Hypoxic encephalopathy	4
Unknown	4

*Percentages do not total 100 because of rounding.

†Category included hypoglycemia, hyperglycemia, hypocalcemia, hyponatremia, hypernatremia, renal failure, and hepatic failure.

tween 4 and 7 in 27 patients (25.7%) and between 8 and 15 in 61 patients (58.0%).

EEG FINDINGS

Table 4 summarizes the results of the EEG studies. Focal interictal epileptiform discharges were the most

Table 4. Routine Electroencephalographic (EEG) and Digital Video-EEG (DVEEG) Findings

EEG Findings	No. (%) of Patients*
Routine EEG†	
Abnormal	93 (88.6)
Focal IEDs	52 (49.5)
PLEDs	20 (19.0)
Burst suppression	17 (16.1)
Generalized spike and wave discharge	15 (14.3)
Triphasic waves	8 (7.6)
Clinical events	22 (20.9)‡
Electrographic seizures	12 (11.4)‡
DVEEG	
Abnormal	103 (98.0)
Focal IEDs	58 (55.2)
PLEDs	23 (21.9)
Burst suppression	12 (11.4)
Generalized spike and wave discharge	17 (16.1)
Triphasic waves	10 (9.5)
Clinical events	42 (40.0)‡
Electrographic seizures	28 (26.7)‡

Abbreviations: IEDs, interictal epileptiform discharges; PLEDs, period lateralizing epileptiform discharges.

*The statistically significant results between the 2 studies are boldfaced.

†At least 30 minutes of a baseline EEG recording before long-term EEG monitoring.

‡ $P = .01$.

common abnormalities during the routine EEG and DVEEG (Table 4). Digital video-EEG was abnormal in 103 (98%) of the 105 patients. The diagnostic yield of the 2 electrodiagnostic techniques was significantly different in recording seizures and documenting clinical episodes. Electrographic seizures were more commonly observed with the DVEEG than with routine EEG ($P = .01$, χ^2 test). Digital video-EEG was also superior in patients who experienced behavioral spells, for example, seizures or nonepileptic events ($P = .01$, χ^2 test). Nonepileptic behavioral spells were observed in 10 patients (9.5%) in the present series.

PROGNOSIS AND OUTCOME

The mean duration of follow-up was 7 months (range, 1-52 months) in 84 patients. The neurological outcome is summarized in **Table 5**. There were 38 deaths (36.1%) in the present series. Approximately 27% of the patients were independent for activities of daily living (Table 5). The outcome of patients with status epilepticus is summarized in **Table 6**. The clinical presentation of NCSE included the following: encephalopathy following seizures in 10 patients (52.6%), confusion with behavioral problems in 7 patients (36.8%), and staring spells with automatisms in 2 patients (10.5%). None of the patients with NCSE had an excellent outcome (Table 6). Refractory status epilepticus ($P < .003$), hypoxic encephalopathy ($P < .004$), and multi-infarct state ($P < .003$) were the factors associated with increased mortality in a univariate analysis. Age, duration of illness, and GCS score were not of prognostic importance ($P > .05$). With multivariate logistic regression only the presence of a multiple cerebral infarction ($P < .03$;

odds ratio, 5.62) was a significant predictive factor for mortality.

COMMENT

Acute neurological disorders are medical emergencies that may require dedicated personnel and resources in specialized centers.^{1-4,14,15} The reasons for admission to the NICU include stroke, head trauma, status epilepticus, subarachnoid hemorrhage, central nervous system infection, metabolic encephalopathies, and primary and secondary brain tumors.^{1-4,14,15,18-23} The clinical examination of these patients may reveal an altered mental status, focal neurological findings, repetitive seizure activity, or evidence for increased intracranial pressure.^{1-4,14-16} Potential serious medical comorbidity (eg, hypotension or cardiac arrhythmias) must also be evaluated and treated.^{22,23} The care and treatment of patients in the NICU involves multiple specialties including neurology, neurosurgery, anesthesiology, critical care, and physical medicine. Importantly, the neurological disorders treated are associated with an increased risk of serious morbidity and mortality.^{15,19,24,25}

Previous studies have confirmed the diagnostic yield, clinical applications, and efficacy of continuous EEG monitoring in the evaluation of NCSE and refractory GCSE.^{1-4,14,18,19,22,24,25} Digital video-EEG monitoring was used in the present series to confirm the presence of recurrent seizure activity, monitor the response to a therapeutic intervention, or identify an electrographic pattern of prognostic importance. Patients with seizures were admitted to the NICU after initially being treated in an emergency department, on a hospital ward, or in another hospital. Those patients undergoing DVEEG monitoring were more likely to have refractory status epilepticus or a persistent encephalopathy subsequent to seizure activity. Nineteen patients in the present series had NCSE confirmed by DVEEG monitoring (Table 6). The features of NCSE may be nonspecific (eg, impaired mentation or altered consciousness) making a clinical diagnosis based on physical examination alone invalid.¹⁻⁴ Patients who initially had GCSE may have NCSE develop requiring EEG monitoring for detection.^{20,21} Most patients with NCSE are seen with an encephalopathy with or without generalized tonic-clonic seizures.⁴ Serial routine EEG studies may not always identify NCSE because of the variability of the electrographic seizure pattern.⁴ Nonconvulsive seizures were detected in 49 (52%) of 94 patients who underwent continuous EEG monitoring for 7 to 10 days following a sustained traumatic brain injury in 1 series.³ The nonconvulsive seizures in this group with moderate to severe brain injuries were diagnosed by EEG pattern alone.³ The delay in diagnosing NCSE and the duration of seizure activity are associated with an increased mortality.⁴ The outcome of the patients in the present series with NCSE was usually unfavorable with 8 (42.1%) of the 19 patients either dying or having a severe disability during follow-up (Table 6). None of the patients experienced an excellent neurological outcome (Table 6). The relative poor prognosis associated with NCSE compared with GCSE has been observed previously.^{4,20} Thirteen (57%) of 23 patients with NCSE died

Table 5. Patient Outcomes*

Outcome	No. (%) of Patients
Death	38 (36.1)
Vegetative state	3 (2.8)
Severe disability	6 (5.7)
Moderate disability	8 (7.6)
Mild disability	14 (13.3)
Healthy	15 (14.2)
Unknown	21 (19.0)

*The neurological outcomes were divided into the following 6 groups using the Glasgow Outcome Scale: death; vegetative state, unable to interact with environment, unresponsive; severe disability, able to follow commands, unable to live independently; moderate disability, able to live independently, unable to return to work or school; mild disability, able to live independently, able to return to work or school with evidence of neurological signs or symptoms; and healthy, no signs or symptoms of neurological disease.

Table 6. Clinical Factors and Outcome of Patients With Status Epilepticus*

Variable	Patients With Generalized Convulsive Status Epilepticus (n = 45)	Patients With Nonconvulsive Status Epilepticus (n = 19)	Patients With Epilepsia Partialis Continua (n = 7)
Sex			
Males	21 (46.7)	9 (47.4)	4 (57.1)
Females	24 (53.3)	10 (52.6)	3 (42.9)
Age distribution, y			
16-29	10 (22.2)	2 (10.5)	1 (14.2)
30-49	12 (26.6)	5 (26.3)	2 (28.5)
50-69	15 (33.3)	5 (26.3)	1 (14.2)
70-89	8 (17.7)	7 (36.8)	3 (42.8)
Service			
Neurology	33 (73.3)	16 (84.2)	6 (85.7)
Neurosurgery	12 (26.7)	3 (15.8)	1 (14.3)
Outcome†			
Death	19 (42.2)	6 (31.6)	3 (42.9)
Vegetative state	2 (4.4)	NA	NA
Severe disability	4 (8.9)	2 (10.5)	NA
Moderate disability	4 (8.9)	3 (15.8)	1 (14.3)
Mild disability	4 (8.9)	3 (15.8)	1 (14.3)
Healthy	5 (11.1)	NA	1 (14.3)
Unknown	7 (15.5)	5 (26.3)	1 (14.3)

Abbreviation: NA, not applicable.

*Data are given as the number (percentage) of patients.

†The neurological outcomes were divided into the following 6 groups using the Glasgow Outcome Scale: death; vegetative state, unable to interact with environment, unresponsive; severe disability, able to follow commands, unable to live independently; moderate disability, able to live independently, unable to return to work or school; mild disability, able to live independently, able to return to work or school with evidence of neurological signs or symptoms; and healthy, no signs or symptoms of neurological disease.

in 1 study.⁴ A less favorable response to antiepileptic drug therapy in patients with NCSE has also been reported.²² Among 518 patients with status epilepticus, the first treatment regimen was successful in 55% of patients with overt GCSE but in only 15% of patients with subtle GCSE.²⁰

The rationale for DVEEG monitoring also includes identification of EEG patterns that are of prognostic importance in patients requiring NICU care.^{18,26} Selected EEG abnormalities (eg, burst suppression pattern) in individuals with an acute neurological disorder are indica-

tors of a poor prognosis.^{22,26} The EEG may also be of predictive value in patients treated for status epilepticus.²⁶ The recognition of electrographic seizures, clinical episodes, or both, during the continuous EEG monitoring may significantly influence the patient's diagnostic evaluation and treatment (Table 4).^{22,26} The diagnostic yield of DVEEG monitoring compared favorably with a routine EEG study in identifying electrographic seizures and observing epileptic or nonepileptic behavioral spells (Table 4). Importantly, almost 10% of the patients in the present series had paroxysmal episodes without an EEG correlate that were difficult to distinguish clinically from seizures. Digital video-EEG permitted the identification of nonepileptic behavioral spells in these individuals and prevented the inappropriate use of an antiepileptic drug regimen. Concomitant videotape recording of the patient during long-term EEG monitoring is pivotal in selected individuals when there is concern regarding behavioral spell classification. Continuous EEG monitoring alone may be sufficient to identify the prognostic importance of an EEG pattern in a patient with a severe encephalopathy or status epilepticus.

The present series would indicate that DVEEG monitoring in the NICU is predominantly being used in patients with refractory status epilepticus, severe encephalopathy, or both. A minority of these patients experienced a favorable outcome, that is, being healthy or having a mild disability. The results of DVEEG monitoring, however, were used to alter patient care treatment in the 105 patients studied and may have improved the neurological outcome and quality of life in those who survived the acute illness. The unfavorable outcome associated with the treatment of refractory status epilepticus has previously been shown.^{21,24,25} Other reasons for the relatively poor outcome in these patients include the underlying symptomatic causes, the duration of the acute neurological illness, or a possible delay in initiating admission to the NICU. The present series was not intended to evaluate the cost-effectiveness of DVEEG monitoring. A previous study showed that continuous EEG monitoring is cost-effective and altered patient care treatment in the NICU.³

A potential limitation of the present series is that the high mortality and morbidity may reflect the acuity of the patient population and the referral of very ill individuals to a single tertiary center for acute neurological care. The findings may not necessarily reflect the experience at other institutions. Further prospective studies, requiring a large patient series, are needed to establish the appropriate use of DVEEG monitoring in the NICU and to determine patient selection and duration of DVEEG monitoring.

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and Fulgham); study supervision (Dr Cascino).

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