Wireless Brain Monitoring in the Emergency Department

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Abstract –**Most hospitals in the world do not perform Electroencephalograms in the emergency departments due to space, cost, training, and complexity of the equipment and the test. New miniature, low-cost, simple, digital, wireless EEG machines have been developed that solve all four of these inhibiting factors to allow EEG, to be used in Emergency Departments to evaluate patients presenting with Altered Mental Status for nonconvulsive seizures. Four-channel wireless EEG used in the ED is feasible, provides good quality screening EEGs, and was able to diagnose underlying seizures or slowing in a significant number of patients.**

Keywords – EEG, Electroencephalogram, Emergency Department, Brain Waves, Nonconvulsive Seizures.

I. INTRODUCTION

Most emergency departments (ED) do not perform electroencephalogram (EEG) studies. This is due to several inhibiting factors including:

1. The bulk of the equipment makes it inconvenient to be permanently located in an ED setting,
2. The cost of equipment at $20,000-$40,000 per unit is very expensive for most ED budgets,
3. The time and expertise required to set up and monitor an EEG is typically lacking in the ED, and
4. ED personnel are not trained to read EEGs and a neurologist may not be immediately available to read the EEG.

In general, EDs around the world do not request an EEG unless a clinical indication of seizure is present (ie: the patient is convulsing). However, "nonconvulsive seizures (NCS) produce altered mentation or behavior with only subtle or absent motor components. For this reason, NCS must be defined by EEG rather than clinical criteria. [1] Thus, those patients that suffer from NCS are rarely diagnosed in the ED.

Delay in diagnosing NCS is common in ERs. In Kaplan's 1996 study, of the 23 patients examined, Nonconvulsive Status Epilepticus NCSE was diagnosed within 24 hours in only 13 patients (57%). Diagnosis required 1-3 days in seven patients (30%), and 4-5 days in three patients (13%). [2]

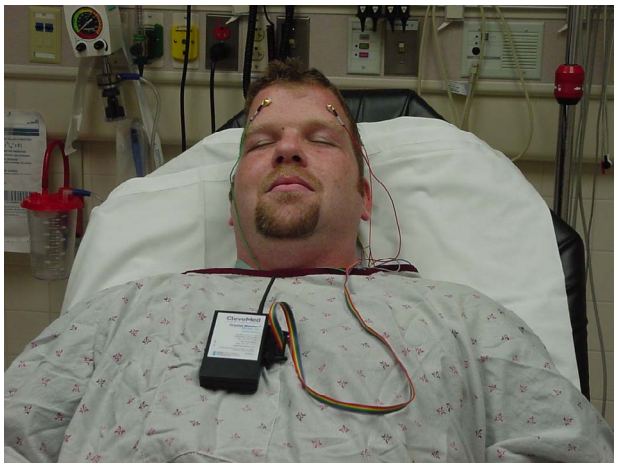

Fig. 1. Patient With the Crystal Monitor 16

Drislane et al. found that 77% of 89 patients with NCSE were not recognized as having seizures prior to their diagnostic EEG. This caused a median delay of 72 hours before the diagnosis of NCSE for those without antecedent clinical convulsions, versus a delay of 24 hours with those who had observed clinical seizures. [3]

When the ED physician is able to suspect that the altered mental status may be caused by NCS and then orders and EEG, either an EEG technician and EEG cart are called from the EEG lab to perform the test in the ED, or the patient is transported to the EEG lab for testing. This may typically add 30-60 minutes or even up to several hours to obtain the results. Also, many EEG labs are not open 24 x 7 (24 hrs./day, 7 days a week), making EEG unavailable for hours or days sometimes. [4]

New technology allows EEG to be conveniently performed in the ED by ED personnel and provide brain monitoring in the same manner that heart monitoring is currently performed in an emergency setting. Previously, many advanced features have

been developed on various medical monitors such as Internet transfer of data that can solve FACTOR 4 above. However, for EEG, they have been applied to large cart mounted machines; too large to be *conveniently and regularly* used in an Emergency Department setting.

New miniature, low-cost, simple, digital, wireless EEG machines have been developed that solve all four of the above inhibiting factors to allow the lowest cost, most widely used neural functional test, EEG,[5] to be conveniently and regularly used in Emergency Department settings (**Figure 1**).

Patients presenting to the ED with Altered Mental Status currently makes up 10% or 14 million of the 140 million yearly ED visits, nationally. To address lack of adequate neurologic real-time monitoring the National Institutes of Health (NIH) awarded a contract to provide support for the development of new technology to non-invasively monitor a patient's neurologic status.

II. METHODS

Guided by NIH recommendations & support Cleveland Medical Devices, Inc. (CleveMed) has created a portable, wireless multi-channel EEG. The Crystal Monitor® Model 16 device used in the initial part of this study was shown in Figure 1. A newer device, with two-way wireless communications allowing for retransmission of data to further enhance reliability has been developed. This Crystal Monitor Model 20E is shown in **Figure 2**. It will be used in future work, but none of the data shown here was recorded with this device.

Figure 2 Crystal Monitor Model 20E for Emergency Department use.

This machine was designed primarily for the ED patient allowing for a screening EEG to be done.

A four-channel coma montage (Fp1-C3, Fp2-C4, C3-O1, C4-O2, GRND FpZ) was used to minimize electrode set-up time.

Telemetry allows the patient to be untethered and moved about freely while still being monitored, an important requirement for any patient being monitored in the ED.

An Internet connection allows a neurologist to interpret the EEG from anywhere.

To evaluate the feasibility, quality and utility of a wireless four-channel EEG on selected patients presenting to the Emergency Department, **w**e conducted a prospective observational study on a convenience sample of patients presenting to the Troy Beaumont ED. Troy Beaumont is a community hospital located in a relatively affluent suburb of Detroit, MI with a yearly ED census of 65,000 patients. Local IRB/HIC approval was obtained. The enrollment of each patient was broken down into three separate stages:

Initial Evaluation and Consent
Obtaining the EEG
Transmission and Reception

All data was analyzed using descriptive statistics.

Initial Evaluation and Consent:

Adult patients age 18 years and older who met the Inclusion/Exclusion criteria (**Table 1**) were eligible for enrollment in the study. All enrolled patients or their appropriate caregiver completed an informed consent prior to study enrollment. This study was only conducted Monday through Friday 9:00am to 5:00pm when both the study coordinators and the neurologists were available.

Attaining the EEG:

All enrolled patients had a 20-minute EEG, utilizing the Crystal Monitor Model 16. This process involved the placement of seven gold-cup electrodes **w**ith electroconductive paste. The EEG was performed by one of two study investigators.

The study investigators were trained by CleveMed as well as EEG technicians from Troy Beaumont in the correct method to attach the electrodes. As this was only a feasibility study, the ED physician and patient were blinded to the results of this EEG; therefore neither specific care nor inpatients EEG were mandated by inclusion into the trial.

Transmission and Reception:

After the EEG was completed the data was compressed and password encrypted. The study coordinators paged the neurologist with information regarding the case and that an EEG was being sent.

Table 1 Inclusion/Exclusion Criteria:

The following patients will be eligible for study inclusion:

1. Patients with known seizure disorder of any type, but with prolonged (> 1 hr.) post-ictal mental status change.
2. Patients with status epilepticus who have received a muscle relaxant for intubation to determine the presence of subclinical seizures.
3. Patients with brief alteration of mental status of unknown origin. (This group includes new onset seizure disorder, syncope, "spells," "blackouts," etc.)
4. Patients with behavioral changes that may indicate nonconvulsive seizures (impaired consciousness, violent outbursts, unusual behaviors, etc.)
5. Acute head injury patients with mental status changes that may indicate nonconvulsive seizures.
6. Patients with a history of previous head injury presenting with new onset mental status changes. (Head injured patients are at risk for post-traumatic seizures).
7. Patients with neurological exams that may be consistent with focal or partial nonconvulsive seizure. (Eg: aphasia, Todd's paralysis, etc.)

The following patients will be excluded from the above groups.

1. Patients who are convulsing.
2. Medically or surgically unstable patients.
3. Family member, other authorized representative unable to give informed consent.
4. Patients with a head injury incompatible with the use of EEG (eg: gunshots, severe scalp abrasions, etc.)

The EEG was transmitted and read by one of two study neurologists. The neurologist would then provide a real-time read for the EEG via telephone conversation or email.

The neurologist also subjectively evaluated the quality of the EEG utilizing the following four-point scale:

4 = Excellent quality, Acceptable
3 = Good quality, Acceptable
2 = Fair quality, Acceptable
1 = Poor quality, Unacceptable

Patients were followed to either attain their discharge diagnosis from the ED or the hospital in the case of admission.

III. RESULTS

Seventy-seven (77) unique patients have been enrolled in the trial. All patients who were enrolled in the trial had an EEG completed with a corresponding interpretation and quality score. 33.7 % of the patients were female. The mean age of the patients was 59.7 years old (SD of 19.7). The minimum age was18, the maximum age was 90. The racial background of the patients included:

- Caucasian, Non-Hispanic= 64/77 (83.1%)
- Caucasian, Hispanic = 1/77 (1.3%)
- Caucasian, Middle Eastern = 5/77 (64.9%)
- African American = 7/77 (9.1%)

The indications for an EEG study were:

- Witnessed or Suspected seizure disorder = 64/77 (83.1%)
- Syncope = 10/77 (13.0%)
- Head Injury with prolonged symptoms = 3/77 (3.9%)

The EEG quality was rated with a mean score was 2.52 (99% CI 2.30 to 2.74) by the neurologists as shown in **Table 2**.

Table 2 ED EEG Quality Rating

EEG Quality	Total
1 = poor quality, unusable	5 (6.5%)
2 = fair quality, acceptable	32 (41.6%)
3 = good quality, acceptable	35 (45.5%)
4 = excellent quality, acceptable	5 (6.5%)
	77 (100%)

The EEG interpretations (5 unusable EEGs were not included) were:

- 37/72 (51.4%) EEGs were interpreted as normal
- 2/37 were diagnosed as pseudoseizure by the ED physician
- 28/72 (38.9%) EEGs were interpreted as slowing
- 11/28 were patients who clinically appeared post-ictal
- 7/72 (9.7%) EEGs identified a nonconvulsive epileptogenic foci

Twenty-four of the seventy-seven 24/77 (31.1%) of the ED EEG patients had a standard EEG at the inpatient EEG Lab. Of those, 18/24 (75%) were equivalent to the study EEG. The six dissimilar results are described in **Table 3**.

Table 3 Analysis of Dissimilar Results from ED to Lab EEG

Patient #	Study EEG result	Inpatient Result
14	Left sided seizure activity	Post-Ictal State
21	Sharp waves bi-frontopolar channels, possible artifact	Normal
30	Mostly wake EEG	Slightly beyond normal limits, suggestive of mild diffuse cerebral irregularity
50	Mostly wake with movement artifact	Diffuse slowing consistent with mild to moderate encephalopathy
57	Mild slowing bilaterally – consistent with mild sedation	Normal EEG
61	Poor Quality EEG	Normal EEG

IV. DISCUSSION

Understanding that EEG is time-sensitive modality, it is important that we perform EEGs when they can be most useful, i.e. in the acute setting. Until now objective functional studies of neurologic status have been unavailable to ED physicians. We believe that wireless EEG is a feasible in the emergency department.

No enrolled patient failed to complete an EEG. Only 5 of 77 patients had unusable EEGs, primarily due to combination of muscular artifact and gaps in the data during the wireless transmission. [However, the wireless transmission of data can be even further improved. A new radio technology using a bi-directional transmission allows retransmission of lost packets. The Crystal Monitor Model 20E shown in Figure 2 has this more robust technology and will be used during future testing.]

Based on this data we also believe that ED EEG provides valuable information to the ED physician, which can expedite safe medical care. We do not assert that a four-channel seizure is superior or equivalent to the standard EEG.

We do believe its use as a screening tool in the ED provides the ED physician with the additional information necessary to make a more appropriate disposition from the ED.

Utilizing EEG as outlined in within the Inclusion/Exclusion criteria allows the ED to identify or exclude disease processes that would otherwise require admission to the hospital.

We plan on conducting a follow-up study and unblinding the result of the ED EEG to the ED physician.

CONCLUSION: Four-channel wireless EEG used in the ED is feasible, provides good quality screening EEGs, and was able to diagnose underlying seizures or slowing in a significant number of patients.

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[4] For example, see Medical College of Georgia website at http://www.neuro.mcg.edu/amurro/aemu_eeg/emergency.htm. Emergency EEGs "are available from 4:30 PM - 10 PM Monday to Friday and 8 AM - 10 PM Saturday and Sunday" This is typical of the majority of hospitals in the US.

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