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Utility of electroencephalography: Experience from a U.S. tertiary care medical center

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HIGHLIGHTS

- An average delay of 4 h exists between the request for EEG monitoring and its initiation.
- Seizures were detected in less than 6% of EEGs, and 45% of emergency department EEGs were normal.
- The observed delay and low diagnostic yield represent significant inefficiencies in EEG practice.

ABSTRACT

Objective: To investigate the utility of electroencephalography (EEG) for evaluation of patients with altered mental status (AMS).
Methods: We retrospectively reviewed 200 continuous EEGs (cEEGs) obtained in ICU and non-ICU wards and 100 spot EEGs (sEEGs) obtained from the emergency department (ED) of a large tertiary medical center. Main outcomes were access time (from study request to hookup), and diagnostic yield (percentage of studies revealing significant abnormality).
Results: Access time, mean ± SD (maximum), was 3.5 ± 3.2 (20.8) hours in ICU, 4.8 ± 5.0 (25.6) hours in non-ICU, and 2.7 ± 3.6 (23.9) hours in ED. Access time was not significantly different for stat requests or EEGs with seizure activity. While the primary indication for EEG monitoring was to evaluate for seizures as the cause of AMS, only 8% of cEEGs and 1% of sEEGs revealed seizures. Epileptiform discharges were detected in 45% of ICU, 24% of non-ICU, and 9% of ED cases, while 2% of ICU, 15% of non-ICU, and 45% of ED cases were normal.
Conclusions: Access to EEG is hampered by significant delays, and in emergency settings, the conventional EEG system detects seizures only in a minority of cases.
Significance: Our findings underscore the inefficiencies of current EEG infrastructure for accessing diagnostically important information, as well as the need for more prospective data describing the relationship between EEG access time and EEG findings, clinical outcomes, and cost considerations.

1. Introduction

Electroencephalography (EEG) is the gold-standard test for diagnosing seizures, especially subclinical emergencies, including non-convulsive status epilepticus (NCSE) (DeLorenzo et al., 1998; Claassen et al., 2004; Laccheo et al., 2015). However, conventional scalp EEG with glued electrodes is very resource-intensive, requiring dedicated, specially trained, personnel and expensive equipment (Kull and Emerson, 2005). Furthermore, the additional time needed for interpretation can delay its impact on patient care up to 22–48 h (Quigg et al., 2001; Kämppi et al., 2013).

The utility of EEG in clinical practice depends on the time needed to setup and obtain an EEG recording (access time) and the proportion of studies that find seizures or other electrographic abnormalities (diagnostic yield). Because the majority of seizures present within the first hour of EEG monitoring, diagnostic yield may be confounded by access time since electrographic events occurring in temporal proximity of neurological injury may be missed if recording is delayed (King et al., 1998; Claassen et al., 2004; Losey and Uber-Zak, 2008; Shafi et al., 2012; Yigit et al., 2012; Lee et al., 2013; Betjemann and Lowenstein, 2015; Westover et al., 2015). This is particularly relevant in emergent

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situations such as NCSE, whose morbidity and mortality increase with delays in treatment and for which the decision to treat with anti-epileptic drugs depends on the timely initiation of EEG recording (Rai et al., 2013; Betjemann and Lowenstein, 2015).

In this study, we determined the utility of continuous and spot EEG by quantifying their access time and diagnostic yield in hospital inpatient – including intensive care unit (ICU) and non-ICU wards – and emergency department (ED) settings. We emphasize that the purpose of our study was not to determine the ability of EEGs to detect seizures, but rather that our study is the first of its kind to offer a realistic glimpse of the severity of delays related to conventional EEG at a modern United States tertiary care medical center.

2. Methods

2.1. Standard protocol approvals, registrations, and patient consents

This study was conducted with the approval of the Stanford University Institutional Review Board.

2.2. Sampling

We included patients age 18 years or older who received cEEGs and sEEGs in inpatient (ICU and non-ICU) wards and the ED, respectively, at Stanford University Medical Center. EEG technologist logs were reviewed from February 1, 2014 to December 31, 2014 for cEEGs and from March 1, 2011 to December 31, 2014 for sEEGs. Within inpatient wards, we included patients to maintain an equal number of cEEGs ordered with routine and stat priority. All sEEGs were ordered stat. Patients were excluded if *EEG access time*, patient location, or order priority could not be determined or were unreliable, or if a sEEG was done immediately prior to the cEEG study. Given the emergent conditions under which ED sEEGs are likely to be ordered and the reduced hookup time required for sEEGs compared to cEEGs, ED sEEGs were included to estimate the lower bound of *EEG access time* at this institution. However, sEEGs are less commonly ordered from the ED, therefore the sampling period was extended to match the number of EEGs samples from other wards.

2.3. Demographics

Patient demographics were coded as dichotomous, categorical variables as follows: age (above or below the median age of our sample population, 60.7 years), gender (male or female), ethnicity (Hispanic or non-Hispanic), race (white or non-white), occupation (employed or unemployed), and health insurance (insured or uninsured). Race and ethnicity were defined according to the classification entered into the Electronic Medical Record (EMR) by the medical team, and were collected because they could be associated with disparities in access to medical care.

2.4. Clinical variables

Clinical measures were also coded as categorical variables as follows: patient location (or clinical ward; ICU, non-ICU or ED), order priority (stat or routine), referring department (neurological specialties [neurology, neurosurgery, neurocritical care] or non-neurological specialties), study day (weekday or weekend), study time (work hours [6am-6pm] or after hours [6pm-6am]), clinical history as three separate variables (neurological [yes/no], multiple organ [yes/no], and surgical [neurological, non-neurological, or none]), indication for EEG as three separate variables (seizure [yes/no], altered mental status [AMS; yes/no], or other [e.g., loss of consciousness, sensorimotor disturbances, aphasia, cooling protocol, syncope, and depression/anxiety; yes/no]), and admission to inpatient services from the ED (yes/no). The length of hospital stay (in days) was obtained from discharge summaries in the EMR, calculated as the time between the patient's admission date and discharge date (or date of death). The length of EEG recording (in hours) was obtained from final EEG reports in the EMR, calculated as the time between the start and the end of EEG recording.

2.5. EEG access time

EEG access time (in hours, presented as mean ± SD) was calculated as the difference between the time when EEG was requested and the time when the first page of EEG recording started, both obtained from the EMR. We used two subsets of EEGs to validate these times against the time at which technicians were alerted to the need for an EEG at a patient's bedside (request time) and the time at which useful signal was recorded (start time). Paired t-tests and 95% confidence intervals for the difference in means (95% CI) were used to compare the *EEG access times* calculated using these alternative request and start times.

The request time in the EMR was validated in a subset of 30 EEGs against technician notes indicating when a technician was alerted to the need for an EEG at a patient's bedside either by a phone call from an epilepsy fellow, or by finding the request in the EMR. The difference in *EEG access time* calculated using EMR times (3.9 ± 2.9 h) and technician times (3.7 ± 3.5 h) was found to be statistically insignificant, $t(29) = 0.56$, $p = 0.58$, 95% CI −0.71 to 1.24. Therefore, EMR request times were used to calculate *EEG access time* for all EEGs.

In a subset of 50 EEGs, the start time in the EMR was validated against the time at which the recording of useful signal began according to the Nihon Kohden (NK) clinical EEG system. The difference in *EEG access time* calculated using EMR times (3.9 ± 4.6 h) and NK times (4.0 ± 4.0 h) was found to be statistically insignificant, $t(49) = 0.13$, $p = 0.90$, 95% CI −0.45 to 0.51. Therefore, EMR study times were used to calculate *EEG access time* for all EEGs.

2.6. Diagnostic yield

The diagnostic yield of EEG study was calculated as the percentage of EEGs that revealed seizures (including generalized or focal seizures and status epilepticus), epileptiform discharges (including isolated spikes and sharp waves, generalized periodic discharges [GPDs], lateralized periodic discharges [LPDs], and stimulus-induced rhythmic, periodic, or ictal discharges [SIRPIDS]), or other clinically relevant discharges or abnormalities (e.g., burst suppression, triphasic waves, and focal or diffuse slowing) over the course of the entire EEG recording. The final interpretation of the attending epileptologist, which would have been used at the time to inform clinical management, was used rather than a second interpretation of the original EEG. Study result was coded as four separate dichotomous categorical variables: seizure (yes/no), epileptiform discharges (yes/no), non-epileptiform abnormalities (yes/no), and normal (yes/no).

2.7. Statistical analysis

Analyses were performed using IBM SPSS 22.0. We calculated descriptive statistics for continuous (mean, SD, median, IQR, range) and categorical (percentages) variables. The statistical significance of differences in continuous and categorical variables associated with categorical predictors was determined with Welch's F test and χ^2 tests, respectively. We used Fisher's exact test to compare categorical variables when a group had fewer than five observations,

and Bonferroni correction for multiple comparisons within categorical variable levels. Games-Howell procedure was used to perform post-hoc pairwise comparisons for significant Welch's *F* tests. An analysis of covariance (ANCOVA) was used to test the confounding effects of variables that differed significantly between study groups on the association between ward and *EEG access time*. We calculated *p* values for these covariates when they were tested alongside ward and order priority.

2.8. Sample size estimation and power analysis

This study aimed to detect clinically significant differences in *EEG access time* of 1–2 h between wards with 80% power and 5% two-sided type I error (Betjemann and Lowenstein, 2015). Without prior estimates to guide *a priori* sample size calculations, a post-hoc power analysis of *EEG access times* from a preliminary sample of 100 inpatient cEEGs (50 from ICU, 3.2 ± 2.2 h; 50 from non-ICU, 4.5 ± 4.5 h) found that 120 EEGs per group were needed to detect this difference of 1.3 h with 80% power and 5% significance level. A post-hoc power analysis of the final dataset of 300 EEGs showed that our study detected differences in *EEG access time* between wards with statistical power ranging from 50% (comparing ICU with ED) to 99% (comparing non-ICU with ED) and with a 5% significance level.

3. Results

We included 300 EEGs from a total of 337 (232 cEEGs and 105 sEEGs) by excluding those in which order priority was unknown ($n = 2$), *EEG access time* was unknown or unreliable ($n = 21$), or the cEEG was performed immediately after a sEEG ($n = 14$). Of the sEEGs, 5 were excluded because *EEG access time* was unknown or unreliable.

Table 1 lists demographic and clinical variables for our sample. Overall, our population had a median age of 60.7 years (IQR 28.8 years) and had a fairly even gender distribution (53% male). About half the population was white and 16% were of Hispanic ethnicity. While 62% of patients had some neurological history, only 28% of EEGs were ordered by a neurologist. For more than half (53%) of the cases, the indication for ordering EEG included AMS (any given study could have more than one indication).

The access time and diagnostic yield of EEG is summarized in Table 2. Overall, *EEG access time* (mean ± SD) was 3.7 ± 4.1 h, ranging from half an hour to more than 24 h. In terms of overall diagnostic yield (i.e., EEG finding), seizures and epileptiform discharges were detected in 6% and 26% of EEGs, respectively, while ~21% of EEGs were normal. Notably, comparing cEEG (grouping ICU and non-ICU cases) and ED sEEG findings showed that cEEG detected more seizures (cEEG: 8%, sEEG: 1%; $p = 0.02$), epileptiform discharges (cEEG: 35%, sEEG: 9%; $p < 0.001$), and non-epileptiform abnormalities (cEEG: 86%, sEEG: 54%; $p < 0.001$), and a greater percentage of sEEGs were normal (cEEG: 9%, sEEG: 45%; $p < 0.001$). Average study length was 38.8 h for cEEG studies and 23.4 min for sEEG studies ($p < 0.001$). Combining routine and stat cEEGs, *EEG access time* was longer for non-ICU cases (4.8 ± 5.0 h) – in which 8% detected seizures, 24% detected epileptiform discharges, and 15% were normal – than for ICU cases (3.5 ± 3.2 h) – in which 8% detected seizures, 45% detected epileptiform discharges, and 2% were normal. *EEG access time* was shortest for ED sEEGs (2.7 ± 3.6 h); 1% of these detected seizures, 9% detected epileptiform discharges, and 45% showed normal activity.

EEG access time differed significantly with patient location and study type (cEEG vs. sEEG), but not with order priority (Table 3). In addition, *EEG access time* did not differ with statistical significance across patient demographics, or time and day of study, however non-neurologist referrals to EEG monitoring had significantly shorter *EEG access time*. Excluding routine EEGs from the inpatient cohort, *EEG access time* of stat EEGs differed significantly between wards ($p = 0.03$). Post-hoc testing revealed that, for stat EEGs, *EEG access time* in the ED was 1.8 h shorter than in non-ICU wards

Table 1
Population characteristics stratified by patient location and order priority.

Variable	All $N = 300$	Non-ICU inpatient		ICU		ED	*p* value
		Routine $N = 50$	Stat $N = 50$	Routine $N = 50$	Stat $N = 50$	Stat $N = 100$	
Demographics							
Age ⩾ Median age (60.7 years), %	50.0	44.0	62.0	50.0	58.0	43.0	0.15
Gender: male, %	52.7	46.0	58.0	70.0	50.0	46.0	0.05
Ethnicity: Hispanic, %	15.7	14.0	18.0	14.0	20.0	14.0	0.86
Race: white, %	51.7	64.0	44.0	48.0	36.0	59.0	**0.02**
Employed, %	20.3	16.0	14.0	20.0	18.0	27.0	0.32
Insured, %	98.3	98.0	100.0	98.0	98.0	98.0	0.97[a]
EEG study information							
Referring department: neurological, %	28.0	50.0	64.0	18.0	30.0	3.0	<**0.001**[a]
Study time: work hours, %	68.3	72.0	56.0	62.0	38.0	91.0	<**0.001**
Study day: Weekday, %	79.7	88.0	64.0	80.0	66.0	90.0	<**0.001**
Patient history							
Neurological, %	61.7	68.0	72.0	62.0	68.0	50.0	**0.05**
Multiple organ, %	27.7	26.0	26.0	44.0	36.0	17.0	**0.007**
Prior neurosurgery, %	13.3	22.0	24.0	14.0	10.0	5.0	**0.004**[a]
Prior other surgery, %	8.3	6.0	8.0	16.0	14.0	3.0	**0.03**[a]
EEG indication							
Seizure, %	17.7	10.0	14.0	22.0	14.0	23.0	0.25[a]
Altered mental status, %	53.0	46.0	58.0	48.0	62.0	52.0	0.46
Other, %	32.7	44.0	34.0	36.0	26.0	28.0	0.27[a]
Hospital utilization							
Admitted to inpatient service, %		100.0		100.0		66.0	
Length of EEG Study, mean ± SD, hours	26.0 ± 31.7	40.0 ± 39.5	31.7 ± 22.1	45.1 ± 33.8	38.4 ± 28.8	0.4 ± 0.1	<**0.001**
Length of hospital stay, mean ± SD, days	12.9 ± 21.2	12.1 ± 13.5	10.3 ± 11.2	24.6 ± 22.6	18.1 ± 17.1	6.2 ± 26.0	<**0.001**

P values were calculated using χ^2 test and Welch's *F* test with a significance level of 0.05. Bolded *p* values indicate statistical significance.
ICU: intensive care unit; ED: emergency department.
[a] Fisher's exact test was used because observed number in at least one cell was less than five patients.

Table 2
EEG access time and diagnostic yield stratified by location and order priority.

	All $N = 300$	Non-ICU inpatient		ICU		ED
		Routine $N = 50$	Stat $N = 50$	Routine $N = 50$	Stat $N = 50$	Stat $N = 100$
Access time[a]						
Mean ± SD	3.7 ± 4.1	5.1 ± 5.7	4.5 ± 4.3	3.3 ± 3.3	3.7 ± 3.1	2.7 ± 3.6
Median (IQR)	2.3 (1.4–4.0)	2.6 (1.5–5.1)	3.0 (2.4–5.1)	2.3 (1.6–3.7)	3.0 (1.6–4.7)	1.5 (1.1–2.6)
Range	0.5–25.6	1.0–25.6	0.7–22.0	0.5–20.8	0.7–14.7	0.5–23.9
Diagnostic yield[b,c]						
Normal, %	20.7	18.0	12.0	4.0	0.0	45.0
Non-epileptiform abnormalities, %	75.3	76.0	82.0	92.0	94.0	54.0
Epileptiform Discharges, %	26.0	24.0	24.0	46.0	44.0	9.0
Seizures, %	5.7	10.0	6.0	6.0	10.0	1.0

ICU: intensive care unit; ED: emergency department.
[a] Welch's F test of *EEG access time* detected significant differences between study groups (defined by ward and priority), $p = 0.02$.
[b] χ^2 test (or Fisher's exact test, where appropriate) detected significant differences between study groups in the number of EEGs that found seizures ($p = 0.05$), epileptiform discharges ($p < 0.001$), non-epileptiform abnormalities ($p < 0.001$), and normal activity ($p < 0.001$).
[c] Within inpatient cEEGs, EEG findings between non-ICU (seizure: 8%, epileptiform discharges: 24%, non-epileptiform abnormalities: 79%, normal activity: 15%) and ICU (seizure: 8%, epileptiform discharges: 45%, non-epileptiform abnormalities: 93%, normal activity: 2%) wards differed significantly for epileptiform discharges (0.002), non-epileptiform abnormalities (0.004), and normal activity (0.002), but not for seizure activity ($p = 1.00$). Differences between ED and inpatient ward findings were significant for epileptiform discharges (non-ICU: $p = 0.004$, ICU: $p < 0.001$), non-epileptiform abnormalities (non-ICU: $p < 0.001$, ICU: $p < 0.001$), and normal activity (non-ICU: $p < 0.001$, ICU: $p < 0.001$), but not for seizure activity (non-ICU: $p = 0.03$, ICU: $p = 0.03$). These χ^2 tests (or Fisher's exact tests, where appropriate) were conducted with Bonferroni-adjusted $\alpha = 0.017$.

($p = 0.03$) and 1 h shorter than in the ICU ($p = 0.19$). *EEG access time* was longer in non-ICU wards than in the ICU, by 0.8 h for stat EEGs ($p = 0.52$) and by 1.9 h for routine EEGs ($p = 0.05$). *EEG access time* was shorter for EEGs that found seizures (by 37 min), epileptiform discharges (by 45 min), and non-epileptiform abnormalities (by 2 min) compared to those that were normal, however these differences were not statistically significant. When entered as covariates, race ($p = 0.67$), referring department ($p = 0.22$), study time ($p = 0.44$), study day ($p = 0.61$), and patient history of neurological conditions ($p = 0.17$), multiple organ dysfunction ($p = 0.09$), prior neurosurgery ($p = 0.97$), or other prior surgery ($p = 1.00$) were not found to significantly impact the association between ward and *EEG access time*.

4. Discussion

Our retrospective chart review of 300 patients at a large American tertiary care medical center found that, on average, EEGs were delivered to the patient's bedside in around 4 h and detected seizures in less than 6% of recordings. However, access time for EEG could be more than 24 h in non-ICU locations, and the seizure detection rate could be as low as 1% in the ED. EEGs that revealed abnormalities, as well as those ordered with stat priority, were associated with lower access time, indicating that clinical judgment of the severity of the patient's condition might get an EEG to the bedside faster, but these differences were not statistically significant. In addition, the statistically significant association between patient location and access time may indicate that current EEG infrastructure is capable of delivering EEGs faster to patients more likely to have neurologic emergencies. Our findings suggest that, even in a modern United States tertiary care setting with state-of-the-art EEG practice and 24-h on-call EEG technician services, there is a noticeable delay in access to EEG that might result in the low percentage of cases in which the EEG detects what the ordering physician suspected to find.

While the EEGs in our sample were largely ordered in situations with a high pre-test probability of seizures or epileptiform abnormalities (for example, no EEGs in our sample were ordered to investigate headache), the diagnostic yield observed was far lower than expected (Matoth et al., 2002; Schwartz et al., 2014). Unlike structural abnormalities seen on MRI or CT imaging (e.g., tumors, strokes, abscesses), functional abnormalities of the brain (especially seizures) may be transient, and the majority, especially those whose presence or absence has prognostic value, occur close to the time of the acute injury or alteration of the mental state which prompted the order for an EEG (King et al., 1998; Chong and Hirsch, 2005; Betjemann and Lowenstein, 2015; Westover et al., 2015). The delay in EEG acquisition observed in our sample is large enough that these abnormalities may have come and gone before the EEG gets to the bedside, resulting in a low seizure to non-seizure ratio detected by the spot EEGs. This may explain the paradox between reports of the low yield of seizures during spot EEG recordings and high estimates of the incidence of non-convulsive seizures and status epilepticus in critically ill and emergency department patients undergoing continuous EEG monitoring (Varelas et al., 2003; Angus-Leppan, 2008; Alroughani et al., 2009; Friedman et al., 2009; McHugh et al., 2009; Scozzafava et al., 2010; Kennedy and Gerard, 2012; Teleb et al., 2012; Betjemann et al., 2013; Kamel et al., 2013; Tu et al., 2013; Zehtabchi et al., 2013; Al-Mufti and Claassen, 2014; Betjemann and Lowenstein, 2015; Laccheo et al., 2015).

A second important finding in our study pertains to the low percentage of epileptic abnormalities found in the spot EEGs even though all were ordered because of possible seizures. We are wary that the goal of a diagnostic study is not always easy to infer from a medical record, and it may be that indicating a clinical suspicion of seizure activity as the cause of AMS in the EEG order may have been a shorthand for the urgency of the order rather than the clinician's expectation for the EEG's result. The finding of normalcy or non-epileptiform EEGs might have equally contributed to management of the patients by confirming or invalidating the presumed clinical diagnosis, or by changing a therapeutic plan, and our study was not designed to quantify the impact of EEG on clinical management or patient outcome (Khan et al., 2005; Praline et al., 2007). However, as noted by others, it is possible that the low percentage of epileptic abnormalities detected in spot EEGs may simply be a byproduct of significant delays in EEG acquisition or much shorter duration of recording (Varelas et al., 2003; Claassen et al., 2004; Angus-Leppan, 2008; Sutter et al., 2011).

While prospective studies are needed to determine the impact of delayed EEG access on EEG findings, clinical outcomes, and cost considerations, it is reasonable to suggest that a timely EEG acquisition would facilitate detection of not only non-convulsive seizures that can persist immediately after clinical seizure manifestations end and may be refractory to empiric anticonvulsive treatment,

Table 3
EEG access time and the associations of categorical predictors with differences in EEG accessibility.

Variable	Mean ± SD	*p* value
Sampling variables		
Ward (ICU vs. ED vs. non-ICU inpatient)		**0.004**
ICU vs. ED	3.5 ± 3.2 vs. 2.7 ± 3.6	0.23[a]
ICU vs. non-ICU inpatient	3.5 ± 3.2 vs. 4.8 ± 5.0	0.07[a]
ED vs. non-ICU inpatient	2.7 ± 3.6 vs. 4.8 ± 5.0	**0.002**[a]
Order priority (stat vs. routine)	3.4 ± 3.7 vs. 4.2 ± 4.7	0.14
Study type (cEEG vs. sEEG)	4.2 ± 4.2 vs. 2.7 ± 3.6	**0.002**
Demographics		
Age (above vs. below median)	3.9 ± 4.0 vs. 3.5 ± 4.2	0.38
Gender (male vs. female)	3.5 ± 4.0 vs. 3.9 ± 4.1	0.32
Ethnicity (Hispanic vs. non-Hispanic)	3.8 ± 4.4 vs. 3.6 ± 4.0	0.78
Race (white vs. non-white)	3.8 ± 4.3 vs. 3.6 ± 3.8	0.69
Employed (employed vs. unemployed)	3.9 ± 4.3 vs. 3.6 ± 4.0	0.69
Insured (insured vs. uninsured)	3.7 ± 4.1 vs. 4.1 ± 3.5	0.81
EEG study information		
Referring department (neurological vs. non-neurological)	4.8 ± 4.5 vs. 3.3 ± 3.8	**0.008**
Study time (work hours vs. after hours)	3.7 ± 4.4 vs. 3.7 ± 3.2	0.99
Study day (weekday vs. weekend)	3.7 ± 4.3 vs. 3.6 ± 3.1	0.90
Patient history		
Neurological (yes vs. no)	3.5 ± 4.0 vs. 3.9 ± 4.3	0.47
Multiple organ (yes vs. no)	3.1 ± 3.6 vs. 3.9 ± 4.2	0.12
Prior neurosurgery (yes vs. no)	4.1 ± 5.0 vs. 3.6 ± 3.9	0.53
Prior other surgery (yes vs. no)	3.7 ± 3.8 vs. 3.7 ± 4.1	0.92
EEG indication		
Seizure (yes vs. no)	3.1 ± 3.6 vs. 3.8 ± 4.2	0.24
Altered mental status (yes vs. no)	3.9 ± 4.5 vs. 3.5 ± 3.6	0.36
Other (yes vs. no)	3.7 ± 3.9 vs. 3.6 ± 4.2	0.83
Hospital utilization		
Admitted to inpatient service (yes vs. no)	3.0 ± 4.1 vs. 2.2 ± 2.1	0.20
EEG result		
Normal (yes vs. no)	3.8 ± 4.7 vs. 3.7 ± 3.9	0.86
Non-epileptiform abnormalities (yes vs. no)	3.7 ± 4.0 vs. 3.7 ± 4.4	0.94
Epileptiform discharges (yes vs. no)	3.1 ± 3.0 vs. 3.9 ± 4.4	0.10
Seizures (yes vs. no)	3.1 ± 2.1 vs. 3.7 ± 4.2	0.28

P values were calculated using Welch's *F* test with a significance level of 0.05. Bolded *p* values indicate statistical significance.
ICU: intensive care unit; ED: emergency department.
[a] *P* values generated using Games-Howell post hoc procedure for statistically significant omnibus comparisons with greater than 2 categories.

but also subclinical seizures that might not be detected without EEG and may not be treated empirically because of the lack of obvious seizure signs (King et al., 1998; Heuer et al., 2012; Kämppi et al., 2013, 2015; Laccheo et al., 2015). Because non-convulsive seizures are associated with increased morbidity and mortality, more rapid acquisition of EEG in these cases might result in valuable changes in management (Heuer et al., 2012; Betjemann and Lowenstein, 2015).

Suboptimal EEG access time may also have economic consequences. The use of EEG in situations where it does not yield useful diagnostic information, here due to the confounding impact of access time on diagnostic yield rather than an inadequate ability of EEG to detect seizures or improper ordering of EEG by physicians, represents waste in healthcare spending (Matoth et al., 2002; Schwartz et al., 2014). The influence of delays in EEG monitoring on its ability to guide diagnosis and treatment complicates cost-benefit analyses of EEG that will be crucial to optimizing healthcare spending. Little research has been done to estimate the burden of EEG diagnostics on hospital resources, accounting for the cost of dedicated staff that ensure reliable EEG acquisition, the cost of prolonged hospital stay because of missed abnormalities on EEG, and the opportunity costs of having staff and resources occupied on a patient whose EEG may not reveal prognostic abnormalities (Ney et al., 2013; Abend et al., 2015). It should be noted that the delays due to EEG inaccessibility at a tertiary care medical center pale in comparison to those in resource-poor areas and hospitals without reliable EEG services. In addition to delays in acquiring the EEG, one might also be aware of further delays in interpreting EEG data, communicating results to the ordering physicians, and initiating treatment, all of which represent significant burdens on the utility of EEG in all healthcare settings (Kämppi et al., 2013, 2015; Schiltz et al., 2013; McLane et al., 2015; Tan, 2015).

While delays in EEG reading and interpretation that have been quantified in previous studies may affect the timing of treatment decisions, reducing EEG setup time may increase the yield of the study for transient functional abnormalities and thereby improve its ability to contribute to patient care (Quigg et al., 2001). Relative to interpretation time, EEG setup time represents a more modifiable target for hospital infrastructure improvements. In the sample of 30 EEGs used to validate the time at which EEG was requested, technicians were also asked to note specific reasons why an EEG might be delayed, which included technician or machine unavailability (33%) and patient unavailability due to other tests or procedures (43%). Imaging, such as MRI, would require cumbersome disconnection from the metal EEG electrodes if they were glued beforehand, so technicians preferred to hookup EEG after such procedures. With this qualitative information in mind, hospitals might consider a two-pronged approach to improving EEG delivery: expanding resources (i.e., EEG machines, MRI-compatible electrodes, technician staffing) or optimizing the use of current resources and investigating and implementing point-of-care diagnostic tools with rapid setup and takedown time that may provide diagnostic information closer to the time of highest suspicion of seizure activity (Quigg et al., 2001; Gurbani et al., 2006; Westover et al., 2015). A recent study of a pediatric ICU found that

combining evidence-based, multidisciplinary workflow improvements and staff education reduced delays in seizure treatment, and though they targeted management downstream from EEG hookup, its method might be applicable to improve the efficiency of EEG ordering and its coordination with other diagnostic and therapeutic actions in adult populations (Williams et al., 2016).

In closing, our findings confirm significant delays between EEG request and acquisition, and highlight one of the inefficiencies of the current EEG practice that will have clinical and economical implications. There is a need for prospective studies to more accurately quantify the relationship between EEG access time, EEG findings, treatment status, time of treatment, and cost considerations, as well as to quantify the impact of improved EEG accessibility on clinical outcome.

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