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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,