HHS Public Access

Author manuscript

J Crit Care. Author manuscript; available in PMC 2020 April 01.

Published in final edited form as:

J Crit Care. 2019 April ; 50: 262–268. doi:10.1016/j.jcrc.2019.01.006.

Prescription patterns for routine EEG ordering in patients with intracranial hemorrhage admitted to a neurointensive care unit

MEHDI GHASEMI, MD[a], **MUHAMMAD UMER AZEEM, MD**[a], **SUSANNE MUEHLSCHLEGEL, MD, MPH**[a,b,c], **FELICIA CHU, MD**[a,‡], and **NILS HENNINGER, MD, PHD**[a,d,*,‡]

[a]Department of Neurology, University of Massachusetts Medical School, Worcester, MA 01655, USA

[b]Department of Surgery, University of Massachusetts Medical School, Worcester, MA 01655, USA

[c]Department of Anesthesia and Critical Care, University of Massachusetts Medical School, Worcester, MA 01655, USA

[d]Department of Psychiatry, University of Massachusetts Medical School, Worcester, MA 01655, USA

Abstract

Purpose: To examine clinical factors, including established electroencephalography (EEG) consensus recommendations, that may influence EEG-prescription in critically-ill intracerebral hemorrhage (ICH) patients in the neurointensive care unit.

Methods: Retrospective analysis of 330 ICH patients admitted to a neurointensive care unit at an academic medical center between 01/2013–12/2015. We compared EEG prescription patterns with current EEG consensus recommendations, and employed univariate and multivariable logistic regression modeling to determine clinical variables associated with EEG ordering.

Results: Seventy-eight (41%) of 190 subjects underwent EEG in accordance with EEG-consensus guidelines, demonstrating an overall accuracy (probability that EEG prescription aligned with EEG consensus recommendations) of 64.6% (95%-CI 59.1–69.7). Factors independently associated with EEG ordering included fulfillment of EEG consensus recommendations, lower admission Glasgow Coma Scale (GCS), and presence of clinical seizures. The unadjusted and adjusted C-statistics for fulfillment of consensus recommendations was 0.74

[*]**Correspondence to:** Nils Henninger, MD, PhD, Dr. med. Departments of Neurology and Psychiatry, University of Massachusetts Medical School, 55 Lake Ave, North, Worcester, MA 01655, Tel: (508) 334-2527; Fax: (508) 856-6778, nils.henninger@umassmed.edu.

[‡]Co-senior authors

Details of authors' contributions

Mehdi Ghasemi contributed to the study concept and design, data acquisition, statistical analysis, interpretation of data, drafting the article and critical revision of the manuscript for important intellectual content. Muhammad Umer Azeem contributed to the data acquisition, interpretation of data, and critical revision of the manuscript for important intellectual content. Felicia Chu contributed to the study concept and design, data analysis, interpretation of data, and critical revision of the manuscript for important intellectual content. Susanne Muehlschlegel contributed to the critical revision of the manuscript for important intellectual content. Nils Henninger contributed to the study concept and design, data acquisition, statistical analysis, interpretation of data, and drafting the article.

Conflicts of Interest

Dr. Henninger serves on the advisory board of Omniox, Inc, as well as consultant for Portola Pharamceuticals, Inc and Astrocyte Pharmaceuticals, Inc. The remaining authors have no conflicts of interest.

(95%-CI 0.69–0.80) and 0.85 (95%-CI 0.81–0.90), respectively. Among 83 subjects undergoing EEG (25.2%), EEG findings informed clinical decision-making in 50 patients (60%).

Conclusions: EEG appeared underused in ICH, since less than 50% of patients who fulfilled guideline criteria underwent EEG. Prescription of EEG was related to factors beyond those included in consensus recommendations. Validation of our findings and their association with outcome is required.

Keywords

Clinical decision-making; Consensus recommendations; Electroencephalography (EEG); Guideline adherence; Intracerebral hemorrhage (ICH); Seizure

Introduction

Intracerebral hemorrhage (ICH) is the most devastating form of stroke carrying a 42% in-hospital mortality and substantial disability in survivors [1, 2]. In addition to the immediate hemorrhage-related brain injury, up to 31% of subjects with ICH subsequently develop seizures [3, 4]. Over 50% of these are only detected by electroencephalography (EEG) [4]. Seizures have been associated with overall worse functional outcomes [5]. Accordingly, early and reliable detection of seizures in patients suffering from ICH is critical to optimize patient care.

EEG remains a key diagnostic modality to detect seizure activity in the neurointensive care unit (neuroICU) when a reliable clinical examination is frequently limited by the patient's depressed sensorium [6, 7]. Consensus recommendations have been developed by the American Clinical Neurophysiology Society (ACNS) [8], American Heart Association (AHA) [9], European Society of Intensive Medicine (ESICM) [10] and other studies [7, 11, 12], to inform physicians when to consider EEG-monitoring in patients with brain injury, including ICH. However, although these guidelines generally favor continuous EEG (cEEG) monitoring due to its higher yield to detect electrographic seizure acitivity than routine EEG [8–10, 13], evidence for favoring cEEG over routine EEG is weak [9, 10], and routine EEG is commonly used initially and has been shown to detect electrographic seizure activity in approximately 1/3 of ICH patients treated in the neuroICU [4, 5, 14]. Since cEEG availability is still limited in many ICUs worldwide, routine EEG is commonly utilized for clinical decision-making such as seizure medication management [15]. Accordingly, it is important to understand how physicians utilize routine EEG.

Specifically, it is uncertain whether physicians adopt available consensus recommendations for use of EEG in patients with ICH and relatively little is known about the clinical factors that are associated with routine EEG prescribing by physicians in clinical practice. Improved understanding of factors that impact physicians' decisions to order EEG in ICH patients is important as incomplete translation and adoption of clinical guidelines into practice has been shown to adversely affect patient care [16–19]. In particular, non-convulsive seizures and other secondary brain injuries often remain unrecognized without EEG [8]. Additionally, finding factors that potentially affect EEG-prescription practices of physicians seems to be an important step to detect possible physician biases and intentional non-adherence to

guidelines to ultimately aid future guideline development, assessment of the validity of modern-day quality indicators, and improvement of guideline-based clinical decision support systems.

The overarching goal of this study was to gain insight into the clinical factors associated with routine EEG prescribing in an ICH cohort admitted to a neuroICU. In particular, we sought to determine whether physicians' practice aligned with consensus recommendations developed for EEG by professional epilepsy societies and what may be unaccounted factors. In secondary analyses, we sought to determine how frequently EEG informed clinical decision-making ("informative EEG") as well as the clinical factors associated with an informative EEG.

Methods

Study cohort

We retrospectively analyzed consecutive patients with spontaneous ICH admitted to the neuroICU at the UMass Memorial Medical Center affiliated with the University of Massachusetts Medical School between January 2013 and December 2015 identified from the local stroke registry. A priori defined exclusion criteria were subarachnoid hemorrhage (SAH), ischemic stroke with hemorrhagic conversion, trauma-related ICH, as well as ICH related to brain surgery and tumors. There was no institutional protocol for obtaining EEG, and all EEGs were obtained at the treating physicians' discretion allowing us to study potential factors relating to physician bias in EEG prescription.

Age, gender, co-morbidities, risk factors (tobacco, alcohol, illicit drug use), pre-admission medications including anti-seizure drug (ASD) therapy, ICH cause, in-hospital neurosurgical interventions (e.g., ventriculostomy and hematoma evacuations), as well as EEG workup were collected on all patients by chart review.

All head computed tomography (CT) and brain magnetic resonance imaging (MRI) were reviewed to determine the ICH location (lobar versus non-lobar as well as supratentorial versus infratentorial). We differentiated lobar hemorrhage from non-lobar hemorrhage given the presumed higher epileptogenic potential of the former [3, 20]. Brainstem and cerebellar hemorrhages were included in the "non-lobar." The Glasgow Coma Scale (GCS) was assessed at the time of presentation by members of the stroke or neuroICU teams. Finally, we determined in-hospital mortality and whether patients' goals-of-care were changed to comfort measures only (CMO). Our study was approved by our Institutional Review Board, which granted a Health Insurance Portability and Accountability Act waiver of informed consent. We adhere to the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) guidelines (www.strobe-statement.org).

Risk factor definitions

We determined the presence of hypertension (established diagnosis, use of antihypertensive medications, or systolic blood pressure of ≥ 140 mm Hg or diastolic blood pressure of ≥ 90 mm Hg on 2 separate occasions in the outpatient setting), hypercholesterolemia (use of lipid-lowering agents, or fasting blood total cholesterol level of ≥ 200 mg/dl or LDL

cholesterol of ≥ 130 mg/dl) and diabetes mellitus (defined according to the National Diabetes Data Group and World Health Organization) [21]. Atrial fibrillation was defined according to the American Heart Association guidelines [22].

EEG interpretation and diagnosis of seizures

Twenty-minute portable video EEG studies were obtained at the discretion of the treating neurointensivist. The decision for conversion to twenty-four-hour cEEG video monitoring was done in consultation with an epileptologist. All cEEG were performed as conversion from routine EEG. All EEGs were 21-channel scalp recordings (Nihon Kohden) using 19 surface electrodes applied in accordance with the International 10–20 system. EEG data was recorded (referentially), converted from analog to digital, filtered (1 Hz to 70 Hz) and stored digitally for analysis. EEG was continuously displayed at the bedside. The cEEG studies were reviewed remotely at least twice per day and additionally if neuroICU staff noticed clinical activity or any concerning EEG patterns.

Interpretation of all original EEGs was performed by board certified neurologists trained in the interpretation of EEG as a board-certified neurophysiologist at the time of performing EEG. In addition, all EEGs interpreted to show electrographic seizures, a high-risk EEG pattern, and all cEEG were reviewed by a board-certified neurophysiologist (F.C). EEG findings were categorized as (i) electrographic seizures, (ii) high-risk EEG (spike and sharp waves, periodic discharges, and lateralized rhythmic delta activity), and (iii) no-epileptic activity (this included any EEG pattern that is not a recognized epileptiform pattern such as generalized slowing as well as a normal EEG) according to previously established criteria [23, 24]. Epileptiform discharges were described as focal or generalized spikes and slow waves, and periodic epileptic discharges. Periodic epileptic discharges were subdivided into lateralized periodic discharges (LPDs), and bilateral periodic discharges (BIPDs). Periodic patterns, as well as clinical and subclinical events, were characterized as spontaneous or stimulus-induced [25–28].

The diagnosis of clinical seizure occurrence was based on direct observation by medical staff, as well as patients, family members, and other eyewitnesses if the description was consistent with seizure semiology.

Indication for EEG

To allow for a structured approach, and to put our data into context with existing guidelines that generally favor cEEG in the neuroICU setting ([8–10], we included criteria utilized for cEEG-monitoring in our study. Based on these consensus recommendations on the use of EEG in critically ill adults and children as well as other studies [7, 11, 12], we determined whether patients met criteria for EEG at the time of request by reviewing all hospital notes using the following criteria: (i) deficit out of proportion or prolonged altered mental status (AMS); (ii) acute change or fluctuation of symptoms; and (iii) whether EEG findings prompted formal brain death assessment or resulted in changes in the goals-of-care (e.g. CMO).

Definition of EEG impact on clinical decision-making

In those patients that underwent EEG during hospitalization, we evaluated whether the EEG results were documented to be “informative”, i.e., whether they had any impact on in-hospital decision-making, including initiation or withholding of ASD; change, continuation, or discontinuation of ASDs; addition of another ASD to the existing ASD regimen; whether EEG findings prompted formal brain death assessment or resulted in changes in the goals-of-care (e.g. CMO). Conversely, if for example an ASD dose escalation was done on clinical grounds after the EEG showed non-specific slowing, this EEG would not have been considered informative.

Treatment electrographic seizures with ASD

Consistent with existing guidelines patients did not receive prophylactic ASD [29]. In the presence of a clear clinical correlate to the periodic or rhythmic patterns (i.e., ictal symptomatic pattern) or if periodic or rhythmic patterns intermittently evolve into non-convulsive seizure activity then patients were treated until the resolution of clinical symptoms or cessation of nonconvulsive seizures.

Statistical Analysis

Unless otherwise stated, continuous variables are reported as mean ± SD or median (25^{th}-75^{th} quartile). Categorical variables are reported as proportions. Normality of data was examined using Shapiro-Wilk test. Between-group comparisons for continuous and ordinal variables were made with Mann-Whitney U test. Categorical variables were compared using the χ^2-test or Fisher’s Exact test, as appropriate. To determine the performance of existing EEG criteria (the ”test”) for obtaining an EEG (the “outcome” of interest) in our cohort, we calculated the sensitivity, specificity, and accuracy.

To determine variables associated with EEG prescription in all ICH patients admitted to the neuroICU we used multivariable logistic regression. Variables associated with EEG prescribing in the univariate analyses ($P < 0.2$) as well as age and gender were individually added and removed to create a parsimonious model. Model fit was assessed using the log-likelihood statistics and Hosmer-Lemeshow goodness-of-fit statistics. Collinearity diagnostics were performed (and its presence rejected) for all multivariable regression models. The area-under-the-receiver-operating-characteristic-curve (AUC; C-statistic) with its 95% confidence intervals (CIs) were calculated as a measure of discrimination and predictive ability of the models to explain physicians’ decision to prescribe an EEG. The same analysis was repeated in the subgroup of ICH patients that fulfilled EEG criteria to determine possible factors associated with EEG prescription in this subgroup of patients (i.e., factors influencing physician decision).

Two-sided significance tests were used throughout and a two-sided $P < 0.05$ was considered statistically significant. All statistical analyses were performed using IBM® SPSS® Statistics Version 22 (IBM®-Armonk, NY).

Results

Study participants

From January 2013 to December 2015, 337 patients were admitted to the ICU with the diagnosis of spontaneous ICH. We excluded two patients with ischemic stroke with hemorrhagic conversion, one patient with traumatic ICH, and 4 patients with subarachnoid hemorrhage leaving 330 patients (49% female, 42% lobar hemorrhage location) for analysis. Data was complete in all patients for all variables.

Table 1 summarizes the baseline characteristics of the cohort stratified by EEG status. Eighty- three patients (25.2%) underwent routine EEG during their hospitalization. Among these, 13 patients (15.7%) also underwent cEEG monitoring (all were done as conversion from routine EEG). The median duration of cEEG in these patients was 48 hours (IQR 24 to 64.5 hours). The average time from admission to EEG was 4.3 ± 3.5 days. On average, patients undergoing EEG were more likely to have a lobar ICH location ($P < 0.05$), neurosurgical intervention ($P < 0.05$), witnessed seizure ($P < 0.001$), as well as history of seizures ($P < 0.01$) and ASDs use prior to their ICH ($P < 0.01$). Among all EEGs, electrographic seizures were present in 6 (7.2%) cases, high-risk EEG findings were present in 7 (8.4%) cases, and no-epileptic activity (i.e, EEG showed no electrographic correlate for seizures) in 70 (84.3%) of patients.

Fulfillment of EEG criteria and EEG prescription

Overall, 190 (58%) patients fulfilled criteria for obtaining EEG per existing consensus recommendations. Of these, 78 (41%) underwent EEG, resulting in a sensitivity (i.e., the probability that EEG criteria were fulfilled when an EEG was done per physician preference) of 94.0% [95%-CI 86.5% to 98.0%]). Conversely, of the 140 patients not fulfilling EEG criteria, 135 did not have an EEG (specificity = 54.7% [95%-CI 48.2% to 61.0%]). The accuracy (i.e., the overall probability that physicians obtained an EEG concordant with consensus recommendations) was 64.6% (95%-CI 59.1% - 69.7%).

To determine possible factors independently associated with EEG prescription in the entire cohort (n = 330), we constructed multivariable logistic regression models. Figure 1 depicts the model performance based on the AUC for (i) EEG criteria fulfilled (model 1), (ii) admission GCS score, and presence of a clinical seizure during hospitalization (model 2), and (iii) the fully adjusted model including EEG criteria, admission GCS, and presence of a clinical seizure during hospitalization (model 3). The AUC of model 1 was 0.74 (95%-CI 0.69–0.80) and of the fully adjusted model (model 3) was 0.85 (95%-CI 0.81–0.90), indicating that clinicians used information from admission GCS and the presence of a clinical seizure during hospitalization in addition to established consensus recommendations for ordering routine EEG in patients with ICH (Table 2). Though suggested by univariate analyses, CMO and in-hospital death status did not improve model performance. When CMO patients were excluded from the analysis, the admission GCS was no longer associated with EEG-prescription (AUC of the fully adjusted model: 0.86, 95%-CI 0.81–0.91).

Because only 41% (n = 78) of subjects that fulfilled EEG criteria ultimately underwent EEG, we sought to understand which factors related to EEG prescribing in all patients that met EEG criteria (n = 190). Table 3 summarizes the baseline characteristics of this subgroup stratified by EEG prescribing. Overall, compared to patients that fulfilled criteria but did not undergo EEG (n = 112), subjects that underwent EEG (n = 78) were less likely made CMO/died in hospital ($P < 0.001$), more frequently had a witnessed seizure prior to hospitalization ($P < 0.001$), had more vascular risk factors (diabetes, coronary artery disease [CAD], peripheral arterial disease [PAD]; all $P < 0.05$), as well as had a higher GCS at presentation (10 ± 3 vs. 8 ± 4, $P < 0.001$). After adjustment, age, admission GCS, CAD, and clinical seizure during hospitalization were independently associated with EEG prescription (Table 4). In sensitivity analyses restricted to patients that were not made CMO, presence of an in-hospital seizure was the only predictor whether an EEG was obtained (OR 3.5, 95%-CI 1.3–9.3, $P = 0.011$).

Finally, among patients that did not meet EEG criteria (n = 140), a seizure history in patients undergoing EEG (40% versus 3%; $P = 0.015$) was the only baseline variable that differed between subjects that did (n = 5) versus did not (n = 135) undergo EEG.

Impact of physician concordance with EEG consensus recommendations on clinical decision-making

Among the 83 patients that underwent EEG, 50 patients (60.2%) had informative EEG, among which 9 patients (69%) had informative cEEG. Patients with informative EEG had a lower admission GCS (10 ± 4 vs. 12 ± 4, $P = 0.01$) and less frequently had a clinical seizure as the reason for EEG prescribing as compared to subjects without informative EEG (8 [16.0%] vs 12 [36.4%]; $P < 0.05$). All other baseline characteristics were similar (Supplemental Table I). The probability that an EEG was informative when the patient fulfilled EEG consensus recommendations was 61.5% (95% CI 58.6 – 64.4%). The probability that EEG was not informative when the patient did not fulfill criteria was 60.0% (95% CI 20.9 – 89.5%), with an overall accuracy of 61.5% (95% CI 50.1 – 71.9%).

Discussion

Physicians caring for patients with ICH should be aware of current consensus recommendations for obtaining EEG in these patients [7–12, 29] to optimize patient screening and detection of electrographic seizures. Arguably, suboptimal patient screening could contribute to the reported high variability in seizure-detection after ICH (ranging from 1.7% to 31%) [4, 5, 14]. Additionally, in ICH the recognition of seizures seems to be neglected, as evidenced the recent “clinical performance measures” investigation that did not include seizures [30]. This is an important issue because seizures have been associated with increased risk for worsening of hemorrhage-associated mass effect and brain herniation, neuronal dysfunction, as well as overall worse functional outcomes [5, 14, 31]. Although several studies have reported on EEG utilization in ICH patients [6, 7], it is uncertain how many of the studied patients fulfilled EEG criteria per existing consensus recommendations [8, 10, 12, 29], and whether EEGs were obtained according to these recommendations. A

better understanding of factors influencing EEG-prescription practices of physicians is needed to detect possible physician biases and intentional non-adherence to guidelines.

In this respect the most important finding of our study was that EEGs were obtained in less than 50% of ICH-patients that fulfilled criteria for obtaining an EEG per existing consensus recommendations [7–12, 29]. Our additional analyses indicated that physicians' decision to prescribe an EEG related to factors beyond those included in consensus recommendations such as the admission GCS and seizure on presentation / during hospitalization. We additionally found that in the subgroup of ICH patients that met consensus criteria, EEG prescription depended on clinical factors such as age, admission GCS, CAD, and clinical seizure during hospitalization. After exclusion of patients that were made CMO, seizure presence on admission and during hospitalization was the only predictor for EEG prescription. Likewise, seizure history more frequently predicted EEG utilization among patients that did not meet EEG criteria per existing consensus recommendations. These data indicate that clinical seizures or related, but unmeasured factors, influenced physicians' decision-making in obtaining EEG irrespective of criteria included in established consensus recommendations. Accordingly, while suggestive, it remains to be clarified whether seizures *per se* were the driving factor informing physician's behvior. The more important finding of our study was that there existed physician bias in the first place and future study is required to define specific factors that relate to EEG and clinical decision-making. Lastly, it is important to remember that there are currently no established guidelines specifically for performing routine EEG in the NeuroICU setting as existing guidelines relate to obtaining cEEG. Yet, arguably, general criteria for obtaining EEG apply to all EEG independent of the anticipated monitoring duration. Moreover, the practice that all cEEG in our cohort were obtained by converting routine EEG to cEEG may be reflective of a practice that relates to many settings with limited cEEG availability. Accordingly, our observations represent real life observations that are expected that translate to many clinical settings.

In this respect it is notable that physician notes indicated that EEG informed their clinical decision-making in 60.2% of cases in our study. This is consistent with previous investigations reporting ASD adjustment in 46% [24] to 52% [32] of ICU patients undergoing EEG [24, 32]. Considering this, and the fact that only 41% of patients who fulfilled criteria in our study underwent EEG, raises concerns that clinical decision-making remained suboptimal in the studied cohort. For example, empiric seizure therapy including primary seizure prophylaxis with ASDs in ICH patients has been linked to worse outcomes and increased mortality [33, 34]. At the same time, the accuracy of our estimates may be limited by the low EEG prescription rate among patients fulfilling criteria. Accordingly, further study is required whether existing physician biases regarding EEG ordering may affect patient care.

Nevertheless, our single center study should be considered hypothesis generating only and not inform clinical decision-making given the limitations inherent to its retrospective design, which precludes establishing causality. Given our study design we cannot assess appropriateness of existing guidelines and, while suspected, it remains to be established whether similar biases in EEG prescribing patterns exist at other institutions. Moreover, while existing guidelines favor cEEG-monitoring, only a small subset of patients underwent

cEEG in our sample. Yet, though cEEG is recommended over routine EEG, guidelines cautioned that this recommendation is based on low quality of evidence [9, 10] and the general indication for EEG-monitoring is the same regardless of the EEG type highlighting the general validity and generalizability of our primary observations. In addition, we were unable to determine the specific reasons as to why an EEG was not performed in a given patient such as due to preexisting or early transition to DNR/DNI or preexisting disability. Nevertheless, neither including CMO and in-hospital death status as covariates nor exclusion of CMO patients substantially affected overall model performance. Arguably, these patients most likely had preexisting disability as well as preexisting or early transition to DNR/DNI, which may assuage concerns regarding major bias. We used the GCS as documented at the time of admission as a surrogate marker of the ICH severity, which may not be reflective of the GCS at the time of EEG. This is of interest because neurointensivists were seemingly more willing to order an EEG in ICH patients with a higher GCS. This may suggest that a decline in GCS was a potential important trigger for obtaining an EEG. Future studies may thus include the change in GCS over time as a potential covariate.

Furthermore, the majority of included patients underwent routine EEG. Although it has been reported that routine EEG may have a similar yield in detecting electrographic seizure as cEEG, suggesting general validity of our results, results were obtained from a modest patient cohort sampled from a general ICU and not a Neuro ICU [24]. This is an important consideration because it has been demonstrated that dection of electrographic seizures depends on risk factors and duration of EEG monitoring [13], for which reason it is generally recommended to monitor neurocritically ill patients for at least 24 hours [8]. While this may have affected findings regarding electrographic seizure prevalence and clinical decision-making based on EEG, it is unlikely to have biased our primary study goal to determine potential factors associated with physician prescription of EEG, irrespective of the type of EEG.

Conclusions

We found that less than 50% of ICH patients that fulfilled guideline criteria underwent EEG and that physicians' decision to prescribe an EEG related to factors beyond those included in established consensus recommendations for obtaining EEG in the neuroICU. Confirmation of similar biases in future, prospective, multicenter studies has the potential to aid future guideline creation and implementation.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

Sources of Funding

Dr. Henninger is supported by 5KO8NS091499 from the National Institute of Neurological Disorders and Stroke (NINDS) of the National Institutes of Health (NIH). Dr. Muehlschlegel is supported by 5K23HD080971 from the NIH/National Institute of Child Health and Human Development (NICHD). The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Abbreviations

ACNS	American Clinical Neurophysiology Society
AHA	American Heart Association
AMS	altered mental status
ASD	anti-seizure drug
BIPDs	bilateral periodic discharges
CAD	coronary artery disease
cEEG	continuous EEG
CMO	comfort measures only
CT	computed tomography
EEG	electroencephalography
ESICM	European Society of Intensive Medicin
GCS	Glasgow Coma Scale
GPDs	generalized periodic discharges
ICH	intracerebral hemorrhage
LPDs	lateralized periodic discharges
MRI	magnetic resonance imaging
neuroICU	neurological intensive care unit
PAD	peripheral arterial disease
SAH	subarachnoid hemorrhage
STROBE	STrengthening the Reporting of OBservational studies in Epidemiology

References

1. Aguilar MI, Brott TG. Update in intracerebral hemorrhage. Neurohospitalist 2011;1:148–59. doi: 10.1177/1941875211409050. [PubMed: 23983850]
2. Dowlatshahi D, Butcher KS, Asdaghi N, Nahirniak S, Bernbaum ML, Giulivi A et al. Poor prognosis in warfarin-associated intracranial hemorrhage despite anticoagulation reversal. Stroke 2012;43:1812–7. doi:10.1161/strokeaha.112.652065. [PubMed: 22556194]
3. De Herdt V, Dumont F, Henon H, Derambure P, Vonck K, Leys D et al. Early seizures in intracerebral hemorrhage: incidence, associated factors, and outcome. Neurology 2011;77:1794–800. doi:10.1212/WNL.0b013e31823648a6. [PubMed: 21975203]
4. Claassen J, Jette N, Chum F, Green R, Schmidt M, Choi H et al. Electrographic seizures and periodic discharges after intracerebral hemorrhage. Neurology 2007;69:1356–65. doi: 10.1212/01.wnl.0000281664.02615.6c. [PubMed: 17893296]

5. Vespa PM, O'Phelan K, Shah M, Mirabelli J, Starkman S, Kidwell C et al. Acute seizures after intracerebral hemorrhage: a factor in progressive midline shift and outcome. Neurology 2003;60:1441–6. [PubMed: 12743228]
6. Rosenthal ES. The utility of EEG, SSEP, and other neurophysiologic tools to guide neurocritical care. Neurotherapeutics 2012;9:24–36. doi:10.1007/s13311-011-0101-x. [PubMed: 22234455]
7. McHugh JC, Downey T, Murphy RP, Connolly S. Analysis of routine EEG usage in a general adult ICU. Ir J Med Sci 2009;178:263–6. doi:10.1007/s11845-009-0317-5. [PubMed: 19296145]
8. Herman ST, Abend NS, Bleck TP, Chapman KE, Drislane FW, Emerson RG et al. Consensus statement on continuous EEG in critically ill adults and children, part I: indications. J Clin Neurophysiol 2015;32:87–95. doi:10.1097/wnp.0000000000000166. [PubMed: 25626778]
9. Hemphill JC 3rd, Greenberg SM, Anderson CS, Becker K, Bendok BR, Cushman M et al. Guidelines for the Management of Spontaneous Intracerebral Hemorrhage: A Guideline for Healthcare Professionals From the American Heart Association/American Stroke Association. Stroke 2015;46:2032–60. doi:10.1161/STR.0000000000000069. [PubMed: 26022637]
10. Claassen J, Taccone FS, Horn P, Holtkamp M, Stocchetti N, Oddo M et al. Recommendations on the use of EEG monitoring in critically ill patients: consensus statement from the neurointensive care section of the ESICM. Intensive Care Med 2013;39:1337–51. doi:10.1007/s00134-013-2938-4. [PubMed: 23653183]
11. Ney JP, van der Goes DN, Nuwer MR, Nelson L, Eccher MA. Continuous and routine EEG in intensive care: utilization and outcomes, United States 2005–2009. Neurology 2013;81:2002–8. doi:10.1212/01.wnl.0000436948.93399.2a. [PubMed: 24186910]
12. Sutter R, Stevens RD, Kaplan PW. Continuous electroencephalographic monitoring in critically ill patients: indications, limitations, and strategies. Crit Care Med 2013;41:1124–32. doi:10.1097/CCM.0b013e318275882f. [PubMed: 23399936]
13. Struck AF, Osman G, Rampal N, Biswal S, Legros B, Hirsch LJ et al. Time-dependent risk of seizures in critically ill patients on continuous electroencephalogram. Ann Neurol 2017;82:177–85. doi:10.1002/ana.24985. [PubMed: 28681492]
14. Gilmore EJ, Maciel CB, Hirsch LJ, Sheth KN. Review of the Utility of Prophylactic Anticonvulsant Use in Critically Ill Patients With Intracerebral Hemorrhage. Stroke 2016;47:2666–72. doi:10.1161/STROKEAHA.116.012410. [PubMed: 27608820]
15. Rodini I, Papaioannou M, Kazis D, Konoglou M, Theodoridou V, Vassiliadou G et al. The utility of routine eeg in a general ICU. Intensive Care Med Exp 2015;3:A986.
16. Lugtenberg M, Burgers JS, Westert GP. Effects of evidence-based clinical practice guidelines on quality of care: a systematic review. Qual Saf Health Care 2009;18:385–92. doi:10.1136/qshc.2008.028043. [PubMed: 19812102]
17. Cabana MD, Rand CS, Powe NR, Wu AW, Wilson MH, Abboud PA et al. Why don't physicians follow clinical practice guidelines? A framework for improvement. JAMA 1999;282:1458–65. [PubMed: 10535437]
18. Davis DA, Taylor-Vaisey A. Translating guidelines into practice. A systematic review of theoretic concepts, practical experience and research evidence in the adoption of clinical practice guidelines. CMAJ 1997;157:408–16. [PubMed: 9275952]
19. Grol R, Grimshaw J. From best evidence to best practice: effective implementation of change in patients' care. Lancet 2003;362:1225–30. doi:10.1016/S0140-6736(03)14546-1. [PubMed: 14568747]
20. Faught E, Peters D, Bartolucci A, Moore L, Miller PC. Seizures after primary intracerebral hemorrhage. Neurology 1989;39:1089–93. [PubMed: 2761703]
21. American Diabetes A. Diagnosis and classification of diabetes mellitus. Diabetes Care 2014;37 Suppl 1:S81–90. doi:10.2337/dc14-S081. [PubMed: 24357215]
22. January CT, Wann LS, Alpert JS, Calkins H, Cigarroa JE, Cleveland JC Jr., et al. 2014 AHA/ACC/HRS guideline for the management of patients with atrial fibrillation: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines and the Heart Rhythm Society. J Am Coll Cardiol 2014;64:e1–76. doi:10.1016/j.jacc.2014.03.022. [PubMed: 24685669]

23. Srinivasan S, Shin H, Chou SH, Pennell PB, Dworetzky BA, Lee JW. Seizures and antiepileptic drugs in patients with spontaneous intracerebral hemorrhages. Seizure 2013;22:512–6. doi: 10.1016/j.seizure.2013.03.011. [PubMed: 23639871]
24. Khan OI, Azevedo CJ, Hartshorn AL, Montanye JT, Gonzalez JC, Natola MA et al. A comparison of continuous video-EEG monitoring and 30-minute EEG in an ICU. Epileptic Disord 2014;16:439–48. doi:10.1684/epd.2014.0715. [PubMed: 25498516]
25. Hirsch LJ, Kull LL. Continuous EEG monitoring in the intensive care unit. Am J Electroneurodiagnostic Technol 2004;44:137–58. [PubMed: 15521467]
26. Kaplan PW. EEG monitoring in the intensive care unit. Am J Electroneurodiagnostic Technol 2006;46:81–97. [PubMed: 16848306]
27. Oddo M, Carrera E, Claassen J, Mayer SA, Hirsch LJ. Continuous electroencephalography in the medical intensive care unit. Crit Care Med 2009;37:2051–6. doi:10.1097/CCM. 0b013e3181a00604. [PubMed: 19384197]
28. Hirsch LJ, LaRoche SM, Gaspard N, Gerard E, Svoronos A, Herman ST et al. American Clinical Neurophysiology Society's Standardized Critical Care EEG Terminology: 2012 version. J Clin Neurophysiol 2013;30:1–27. doi:10.1097/WNP.0b013e3182784729. [PubMed: 23377439]
29. Morgenstern LB, Hemphill JC 3rd, Anderson C, Becker K, Broderick JP, Connolly ES Jr. et al. Guidelines for the management of spontaneous intracerebral hemorrhage: a guideline for healthcare professionals from the American Heart Association/American Stroke Association. Stroke 2010;41:2108–29. doi:10.1161/STR.0b013e3181ec611b. [PubMed: 20651276]
30. Hemphill JC 3rd, Adeoye OM, Alexander DN, Alexandrov AW, Amin-Hanjani S, Cushman M et al. Clinical Performance Measures for Adults Hospitalized With Intracerebral Hemorrhage: Performance Measures for Healthcare Professionals From the American Heart Association/ American Stroke Association. Stroke 2018;49:e243–e61. doi:10.1161/str.0000000000000171. [PubMed: 29786566]
31. Cusack TJ, Carhuapoma JR, Ziai WC. Update on the Treatment of Spontaneous Intraparenchymal Hemorrhage: Medical and Interventional Management. Curr Treat Options Neurol 2018;20:1. doi: 10.1007/s11940-018-0486-5. [PubMed: 29397452]
32. Kilbride RD, Costello DJ, Chiappa KH. How seizure detection by continuous electroencephalographic monitoring affects the prescribing of antiepileptic medications. Arch Neurol 2009;66:723–8. doi:10.1001/archneurol.2009.100. [PubMed: 19506131]
33. Battey TW, Falcone GJ, Ayres AM, Schwab K, Viswanathan A, McNamara KA et al. Confounding by indication in retrospective studies of intracerebral hemorrhage: antiepileptic treatment and mortality. Neurocrit Care 2012;17:361–6. doi:10.1007/s12028-012-9776-z. [PubMed: 22965324]
34. Messe SR, Sansing LH, Cucchiara BL, Herman ST, Lyden PD, Kasner SE. Prophylactic antiepileptic drug use is associated with poor outcome following ICH. Neurocrit Care 2009;11:38–44. doi:10.1007/s12028-009-9207-y. [PubMed: 19319701]

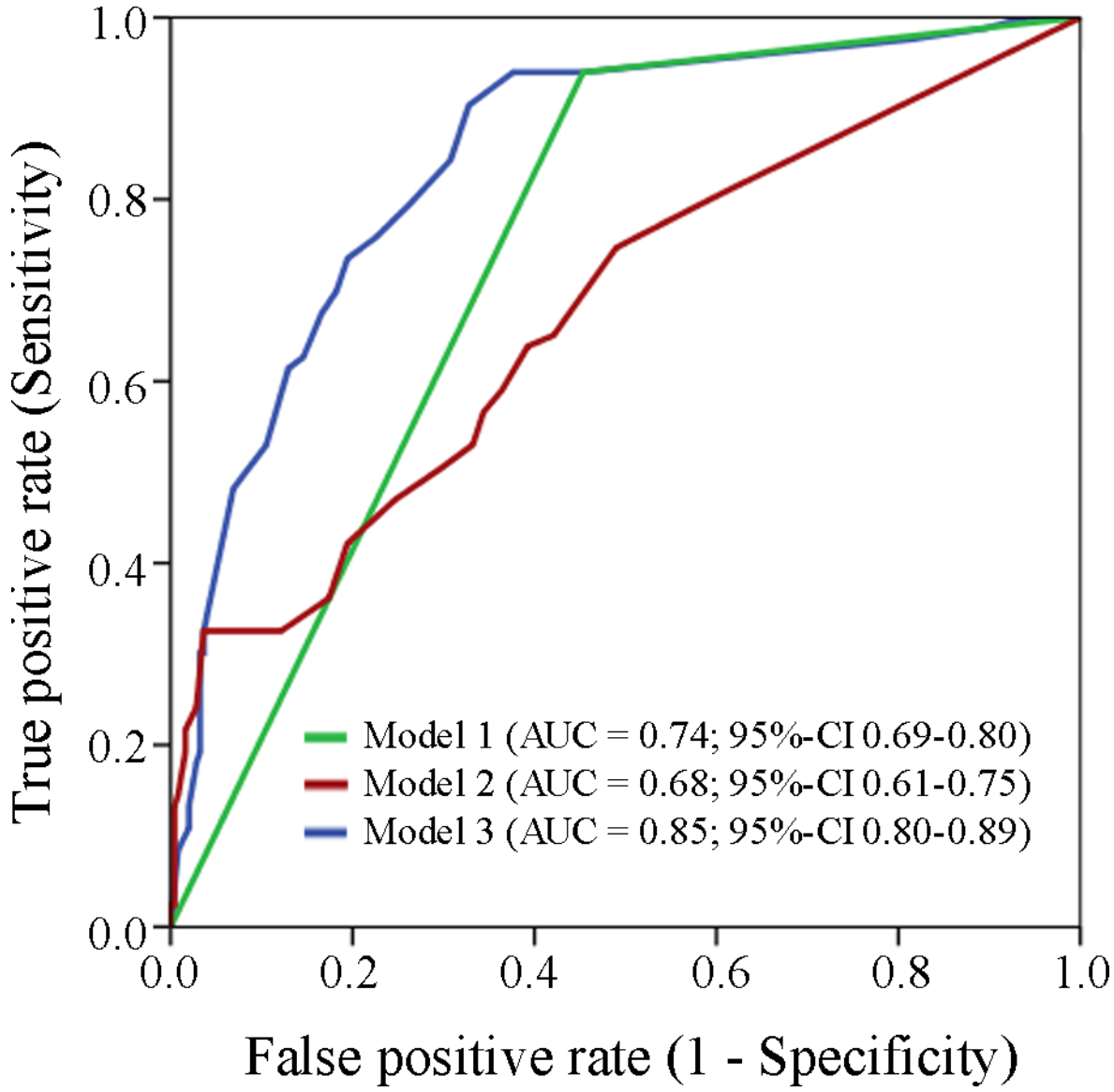

Figure 1. Receiver-operating-characteristics curve analysis for EEG prescription in patients with intracranial hemorrhage (ICH) admitted to a neurointensive care unit.

Comparison of the curves suggested that physicians based their decision to prescribe routine EEG in patients with ICH on clinical criteria beyond those included in criteria. Model 1: EEG criteria fulfilled. Model 2: Admission Glasgow Coma Scale (GCS) score and presence of a clinical seizure during hospitalization. Model 3: Fully adjusted model, EEG criteria fulfilled, admission GCS, and presence of a clinical seizure during hospitalization. Forcing CMO/in-hospital death into the model did not meaningfully change the results (not shown). In sensitivity analyses excluding patients that were made CMO or died in hospital presence of a clinical seizure during hospitalization ($P = 0.025$) and EEG criterial fulfilled ($P < 0.001$) were the only predictors of EEG prescription (AUC 0.86, 95%-CI 0.81–0.91).

Table 1.

Demographic data of all ICH patients (330) stratified by EEG prescription.

Parameters	Group N (% of total patients=330)	Patients without EEG (247)	Patient with EEG (83)	*P* Value
Gender N (%)				0.612
Female	163 (49.4)	124 (50.2)	39 (47.0)	
Male	167 (50.6)	123 (49.8)	44 (53.0)	
Age (Mean ± S.D.)	69 ± 15	70 ± 15	66 ±16	0.827
Admission GCS (Mean ± S.D.)	11.1 ± 4.2	11.3 ± 4.4	10.7 ± 3.9	0.092
ICH location N (%)				**0.046**
Lobar	140 (42.4)	97 (39.3)	43 (51.8)	
Non-lobar*	190 (57.6)	150 (60.7)	40 (48.2)	
ICH location N (%)				0.511
Supratentorial	277 (83.9)	204 (82.6)	73 (88.0)	
Infratentorial	47 (14.2)	38 (15.4)	9 (10.8)	
Both	6 (1.8)	5 (2.0)	1 (1.2)	
Neurosurgical intervention N (%)				**0.021**
No intervention	306 (92.7)	234 (94.7)	72 (86.7)	
Ventriculostomy placement	14 (4.2)	9 (3.6)	5 (6.0)	
Surgical evacuation	10 (3.0)	4 (1.6)	6 (7.2)	
Made CMO/in hospital death N (%)	102 (30.9)	79 (32.0)	23 (27.7)	0.466
Comorbidities N (%)				
Hypertension	261 (79.1)	197 (79.8)	64 (77.1)	0.608
Hyperlipidemia	132 (40.0)	93 (37.7)	39 (47.0)	0.133
Diabetes	75 (22.7)	53 (21.5)	22 (26.5)	0.342
Previous stroke/TIA	60 (18.2)	39 (15.8)	21 (25.3)	0.052
Atrial fibrillation	76 (23.0)	55 (22.3)	21 (25.3)	0.570
CAD	62 (18.8)	40 (16.2)	22 (26.5)	**0.037**
Congestive heart failure	23 (8.2)	14 (5.7)	9 (10.8)	0.109
PAD or carotid artery disease	19 (5.8)	11 (4.5)	8 (9.6)	0.079
Seizure/Epilepsy history	27 (8.2)	14 (5.7)	13 (15.7)	**0.004**
Social History N (%)				
Tobacco	60 (18.2)	40 (16.2)	20 (24.1)	0.106
Alcohol	63 (19.1)	45 (18.2)	18 (21.7)	0.487
Illicit drugs	22 (6.7)	17 (6.9)	5 (6.0)	0.786
Medication Prior Admission N (%)				
Anti-Hypertensives	215 (65.2)	159 (64.4)	56 (67.5)	0.608
Anti-Hyperlipidemics	116 (35.2)	85 (34.4)	31 (37.3)	0.628

Parameters	Group N (% of total patients=330)	Patients without EEG (247)	Patient with EEG (83)	*P* Value
Anti-Diabetics	59 (17.9)	39 (15.8)	20 (24.1)	0.088
Antiplatelets	121 (36.7)	90 (36.4)	31 (37.3)	0.881
Anticoagulants	80 (24.2)	58 (23.5)	22 (26.5)	0.578
Anti-seizure drugs	19 (5.8)	9 (3.6)	10 (12.0)	**0.004**
Meeting Any Criteria for EEG	190 (57.6)	112 (45.3)	78 (94.0)	**<0.001**
Criteria for EEG				**<0.001**
Deficit out of proportion/Prolonged AMS	4 (1.2)	1 (0.4)	3 (3.6)	**0.021**
Acute change or fluctuation of symptoms	181 (54.8)	107 (43.3)	74 (89.2)	**<0.001**
Prognostication **	5 (1.5)	4 (1.6)	1 (1.2)	0.789
Clinical Seizure on presentation/during hospitalization	36 (10.9)	9 (3.6)	27 (32.5)	**<0.001**

* 62 basal ganglia, 51 thalamic, 10 brainstem, 32 cerebellar, and 17 multifocal ICHs as well as 18 primary IVH. A total of 14 subjects developed hydrocephalus requiring EVD placement.

** Documentation as to whether EEG findings prompted formal brain death assessment or resulted in changes in the goals-of-care (e.g. CMO).
CAD, coronary artery disease; CMO, comfort measure only; PAD, peripheral arterial disease; TIA, transient ischemic attack.

Table 2.

Multivariable logistic regression analysis for factors independently associated with EEG prescription in patients with intracranial hemorrhage (ICH, total 330 patients).

Independent variable	Adjusted OR (95%-CI)	*P* value
Any EEG criteria fulfilled	24.1 (8.6–67.1)	< 0.001
In-hospital seizure	5.3 (2.3–12.3)	< 0.001
Admission GCS	1.1 (1.0–1.2)	0.002

Numbers of patients in each category are shown. Odds ratios indicate the increased or decreased odds of the clinical factor being present and for a 1 point increase in the admission Glasgow Coma Scale (GCS) score. The units for the GCS score are points on a scale from 3 to 15. Hosmer-Lemeshow goodness of fit χ^2 11.3, $P = 0.125$.

Table 3.

Baseline characteristics of subjects that met EEG criteria as stratified by EEG prescription. CAD, coronary artery disease; CMO, comfort measure only; PAD, peripheral arterial disease; TIA, transient ischemic attack.

Parameters	Group N (% of total patients=190)	Without EEG (112)	With EEG (78)	*P* Value
Gender N (%)				0.367
Female	100 (52.6)	62 (55.4)	38 (48.7)	
Male	90 (47.4)	50 (44.6)	40 (51.3)	
Age (Mean ± S.D.)	69 ± 15.7	71 ± 15	66 ± 16	0.055
Admission GCS (Mean ± S.D.)	9 ± 4	8 ± 4	10 ± 4	**0.0001**
ICH location N (%)				0.405
Lobar	93 (48.9)	52 (46.4)	41 (52.6)	
Non-lobar	97 (51.1)	60 (53.6)	37 (47.4)	
ICH location N (%)				0.248
Supratentorial	155 (81.6)	87 (77.7)	68 (87.2)	
Infratentorial	31 (16.3)	22 (19.6)	9 (11.5)	
Both	4 (2.1)	3 (2.7)	1 (1.3)	
Surgery N (%)				0.276
No intervention	168 (88.4)	101 (90.2)	67 (85.9)	
Ventriculostomy placement	13 (6.8)	8 (7.1)	5 (6.4)	
Surgical evacuation	9 (4.7)	3 (2.7)	6 (7.7)	
Subsequent CMO/Death N (%)	88 (46.3)	65 (58.0)	23 (29.5)	**0.0001**
Comorbidities N (%)				
Hypertension	143 (75.3)	82 (73.2)	61 (78.2)	0.433
Hyperlipidemia	83 (43.7)	46 (41.1)	37 (47.4)	0.384
Diabetes	38 (20.0)	17 (15.2)	21 (26.9)	**0.046**
Previous stroke/TIA	41 (21.6)	21 (18.8)	20 (25.6)	0.256
Atrial fibrillation	45 (23.7)	23 (20.5)	22 (28.2)	0.221
CAD	43 (22.6)	19 (17.0)	24 (30.8)	**0.025**
Congestive heart failure	18 (9.5)	8 (7.1)	10 (12.8)	0.189
PAD or carotid artery disease	11 (5.8)	3 (2.7)	8 (10.3)	**0.028**
Seizure/Epilepsy history	21 (11.1)	10 (8.9)	11 (14.1)	0.263
Social History N (%)				
Tobacco	33 (17.4)	15 (13.4)	18 (23.1)	0.083
Alcohol	38 (20.0)	22 (19.6)	16 (20.5)	0.883
Illicit drugs	10 (5.3)	6 (5.4)	4 (5.1)	0.945
Medication Prior Admission N (%)				
Anti-Hypertensives	121 (63.7)	68 (60.7)	53 (67.9)	0.308

Parameters	Group N (% of total patients=190)	Without EEG (112)	With EEG (78)	*P* Value
Anti-Hyperlipidemics	70 (36.8)	40 (35.7)	30 (38.5)	0.699
Anti-Diabetics	31 (16.3)	12 (10.7)	19 (24.4)	**0.012**
Antiplatelets	71 (37.4)	40 (35.7)	31 (39.7)	0.572
Anticoagulants	45 (23.7)	24 (21.4)	21 (26.9)	0.381
Anti-seizure drugs	16 (8.4)	7 (6.3)	9 (11.5)	0.197
Clinical Seizure on presentation/during hospitalization	36 (18.2)	9 (8.0)	27 (34.6)	**< 0.001**
Criteria for EEG				
Deficit out of proportion/Prolonged AMS	4 (2.1)	1 (0.9)	3 (3.8)	0.163
Acute change or fluctuation of symptoms	181 (95.3)	107 (95.5)	74 (94.9)	0.832
Prognostication	5 (2.6)	4 (3.6)	1 (1.3)	0.332

Table 4.

Multivariable logistic regression analysis for factors independently associated with EEG prescription in patients with intracranial hemorrhage (ICH) who met the criteria for obtaining EEG (n = 190). CAD, coronary artery disease.

Independent variable	Adjusted OR (95%-CI)	*P* value
In-hospital seizure	4.86 (2.06–11.42)	<0.001
Admission GCS	1.14 (1.05–1.23)	0.002
Age	0.98 (0.96–1.0)	0.033
CAD	2.37 (1.09–5.14)	0.030

Odds ratios indicate the increased or decreased odds of the clinical factor being present and for a 1 point increase in the admission Glasgow Coma Scale (GCS) score and a 1 year increase in the patient age. The units for the GCS score are points on a scale from 3 to 15. Hosmer-Lemeshow goodness of fit χ^2 11.9, $P = 0.155$. When CMO was forced into the model, results were similar except that age ($P = 0.085$) and CMO status ($P = 0.241$) were not associated with EEG prescription (not shown).