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RESEARCH ARTICLE

Hospital EEG Capability and Associations With Interhospital Transfer in Status Epilepticus

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Abstract

Background and Objectives

EEG is widely recommended for status epilepticus (SE) management. However, EEG access and use across the United States is poorly characterized. We aimed to evaluate changes in inpatient EEG access over time and whether availability of EEG is associated with interhospital transfers for patients hospitalized with SE.

Methods

We performed a cross-sectional study using data available in the National Inpatient Sample data set from 2012 to 2018. We identified hospitals that used continuous or routine EEG during at least 1 seizure-related hospitalization in a given year using ICD-9 and ICD-10 procedure codes and defined these hospitals as EEG capable. We examined annual change in the proportion of hospitals that were EEG capable during the study period, compared characteristics of hospitals that were EEG capable with those that were not, and fit multivariable logistic regression models to determine whether hospital EEG capability was associated with likelihood of interhospital transfer.

Results

Among 4,550 hospitals in 2018, 1,241 (27.3%) were EEG capable. Of these, 1,188 hospitals (95.7%) were in urban settings. From 2012 to 2018, the proportion of hospitals that were EEG capable increased in urban settings (30.5%–41.1%, Mann-Kendall [M-K] test $p < 0.001$) and decreased in rural settings (4.0%–3.2%, M-K $p = 0.026$). Among 130,580 patients hospitalized with SE, 80,725 (61.8%) presented directly to an EEG-capable hospital. However, EEG use during hospitalization varied from 8% to 98%. Initial admission to a hospital without EEG capability was associated with 22% increased likelihood of interhospital transfer (adjusted RR 1.22, [95% CI, 1.09–1.37]; $p < 0.01$). Among those hospitalized at an EEG-capable hospital, patients admitted to hospitals in the lowest quintile of EEG volume were more than 2 times more likely to undergo interhospital transfer (adjusted RR 2.22, [95% CI 1.65–2.93]; $p < 0.001$).

Discussion

A minority of hospitals are EEG capable yet care for most patients with SE. Inpatient EEG use, however, varies widely among EEG-capable hospitals, and lack of inpatient EEG access is associated with interhospital transfer. Given the high incidence and cost of SE, there is a need to better understand the importance and use of EEG in this patient population to further organize inpatient epilepsy systems of care to optimize outcomes.

Clinical guidelines recommend electroencephalography (EEG) to detect subclinical seizures and guide therapy for patients hospitalized with status epilepticus (SE).[1,2] However, access to and use of inpatient EEG across the United States is poorly characterized and likely variable. Among patients with seizure evaluated in California, less than 5% underwent EEG monitoring

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in either the inpatient or outpatient setting, and rates of EEG use differed by race, ethnicity, and socioeconomic status.[3] It is unclear whether these findings are representative of care across the United States and whether the proportion differs among hospitalized patients with SE. Given the widely recommended use of EEG, it is critical that we better understand the current distribution of inpatient EEG services and how limited resources may be influencing clinical care.

Interhospital transfers are a likely downstream consequence of not having access to EEG because they offer physicians an option for ensuring patients with SE are able to undergo EEG and access specialized neurologic care. Prior research suggests interhospital transfers are indeed common among patients with SE with studies estimating 20% of patients in the emergency department (ED) and 5% of patients hospitalized with SE undergoing interhospital transfer compared with 1.5% of the general hospitalized population.[4-6] Because some transfers can result in delayed care, poor outcomes, and increased costs to the healthcare system, it is important to more definitively understand the drivers of interhospital transfer in this patient population. This information will be critical for determining which transfer decisions are medically necessary and how to intentionally distribute resources across our healthcare system.[7-10] To address these gaps, we estimated the proportion of hospitals with inpatient EEG capability nationally over time, compared hospital characteristics among EEG-capable and EEG-incapable hospitals, and examined whether lack of EEG capability was associated with interhospital transfers for patients hospitalized with SE.

Methods

Study Design

We performed a cross-sectional study of inpatient hospitalizations for SE from January 1, 2012, to December 31, 2018, using data from the National Inpatient Sample (NIS), developed for the Healthcare Cost and Utilization Project and sponsored by the Agency for Healthcare Research and Quality (AHRQ).[11] The NIS data set is the largest national source of all payer inpatient hospitalizations with more than 7 million hospitalizations from more than 4,000 hospitals per year. Beginning in 2012, the data set captures a 20% stratified sample of discharges from all participating US acute care hospitals. We used the NIS data set to determine hospital EEG capability and its association with interhospital transfers among patients hospitalized with SE.

Study Population

We included patients aged 18 years or older who were admitted to the hospital directly from the ED in the same facility with a primary discharge diagnosis of SE. SE was identified using *International Classification of Diseases*, (ICD) *Ninth Revision* (ICD-9) codes (345.2 and 345.3) from January 1, 2012, to September 30, 2015, and ICD-10 codes (G40.001, G40.011, G40.101, G40.111, G40.201, G40.211, G40.301, G40.311, G40.401, G40.411, G40.501, G40.801, G40.803, G40.811, G40.813, G40.821, G40.823, G40.901, G40.911, G40.A11, G40.A01, G40.B11, and G40.B01) from October 1, 2015, to December 31, 2018[12,13] (eFigure 1 in the Supplement, links.lww.com/CPJ/A407).

Because the study focuses on interhospital transfers, we limited the study to index hospitalizations to prevent inclusion of patients who had already been transferred in previously. We thus excluded patients who were admitted through interfacility transfer from a different ED or acute care hospital. We excluded patients with cardiac arrest (ICD-9 code 427.5; ICD-10 codes I46.0, I46.2, I46.8, and I46.9) who undergo interhospital transfer for multiple reasons beyond SE management (i.e., transfer for targeted temperature management) to avoid biasing our study outcomes.

Measurements

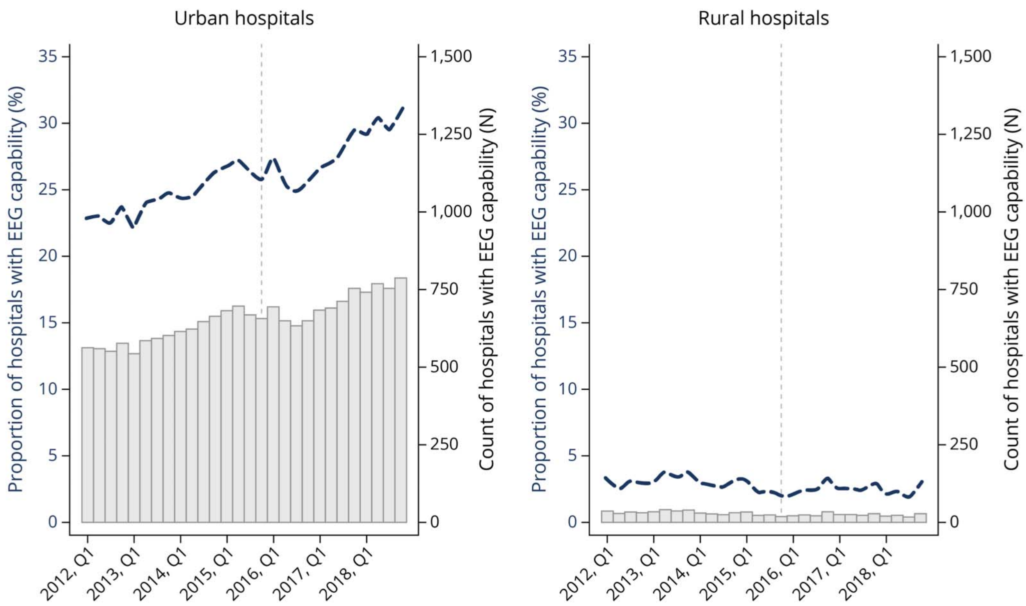
Hospital Measurements

The primary exposure was hospital EEG capability. An EEG-capable hospital was defined as a hospital with at least 1 seizure-related hospitalization in a given calendar year that included the use of continuous EEG (cEEG) or routine EEG (rEEG), defined by ICD codes (rEEG: ICD-9 89.14 and ICD-10 4A00X4Z; cEEG: ICD-9 89.19 and ICD-10 4A10X4Z). We found this definition to have moderate sensitivity (70%) and specificity (83%) using hospital revenue codes as a diagnostic gold standard that was not available in this national data set (eTable 1A in the Supplement, links.lww.com/CPJ/A407). We also evaluated the exposure variables, cEEG capability and rEEG capability, separately. Seizure-related hospitalizations included any encounter with a discharge diagnosis code for epilepsy, SE, convulsions, or conversion disorder with seizure or convulsions using ICD-9 codes 345.x and 780.3 and ICD-10 codes G40.xxx, R56, and F44.5.[13-16]

We created 2 alternative definitions for EEG capability to address limitations in the sensitivity and specificity of our definition. To maximize sensitivity and identify circumstances where patients with non–seizure-related hospitalizations undergo inpatient EEG, we created a broad definition of EEG capability that entailed having at least 1 hospitalization for any cause during which rEEG or cEEG was used in a calendar year. To maximize specificity and to eliminate circumstances in which EEG codes were erroneously entered, we created a narrow definition of EEG capability that entailed having 5 or more hospitalizations that were seizure related and during which cEEG or rEEG was used in a calendar year.

Our second exposure of interest was hospital EEG volume. We calculated the number of seizure-related hospitalizations in which EEG (rEEG or cEEG) was used in a calendar year. This number was heavily skewed; thus, we divided hospital

Figure US Hospitals With Inpatient EEG Capability Using International Classification of Diseases (ICD) Coding



Dashed Horizontal Lines Indicate Proportion of Hospitals. Vertical Bars Represent Counts of Hospitals. Vertical Dashed Lines at 2015 Q4 Indicate Transition From ICD-9 to ICD-10.

EEG volume into quintiles when included as an exposure for our regression analyses.

Additional hospital characteristics included categorical indicators of hospital size (small, medium, and large), geographic region (Northeast, Midwest, South, and West), and hospital ownership (government nonfederal, private not-for-profit, and private investor own), and dichotomous indicators of location in an urban or rural setting and whether the hospital served as a teaching hospital. Hospital size, defined by the NIS, is categorized according to the number of beds, geographic region, whether the hospital is located in a rural setting, and whether the hospital is considered a teaching hospital. Hospitals residing in counties indicated as Core-Based Statistical Area (CBSA) "division" or "metro" based on 2000 and 2010 Census data were considered urban hospitals and hospitals residing in counties indicated as CBSA "rural" or "micropolitan" were considered rural hospitals.

Patient Measurements

Patient sociodemographic characteristics included age, sex, race, primary expected insurance payer, and median household income. Clinical characteristics included medical comorbidities, whether the patient underwent endotracheal intubation, and the use of EEG. Medical comorbidities were assessed using the Charlson comorbidity index for each patient. Endotracheal intubation and the use of EEG were identified using ICD procedure codes. For intubation, this included codes for intubation (ICD-9 96.04; ICD-10 0BH17EZ and 0BH18EZ) or mechanical ventilation (ICD-9 96.7x; ICD-10 5A1935Z, 5A1945Z, and 5A1955Z).[17,18] For EEG, this was the same as described for hospitals earlier.

Outcomes

The primary outcome was discharge through interhospital transfer to a different acute care hospital.

Statistical Analysis

We determined the proportion of hospitals that were EEG capable annually from 2012 through 2018. To address the possibility of misclassification and imperfect sensitivity of our measurement, we also calculated the expected proportion of hospitals that would be EEG capable if ICD coding was 70% sensitive. We examined change over time using the Mann-Kendall (M-K) statistical test for trend. We then repeated the analyses stratifying by hospital location in urban vs rural settings to examine differences by geographic setting. We also determined the proportion of hospitals with cEEG capability annually from 2012 to 2018.

We compared differences in characteristics of hospitals that were EEG capable and EEG incapable using Pearson χ^2 tests for categorical and binary data. We also calculated the predicted probability of a hospital having EEG capability for each level of a hospital characteristic by estimating the marginal estimates using the Stata "margins" post-estimation command, holding all other covariates at their mean values. We restricted these descriptive analyses to 2018 to avoid incorporating 1 hospital multiple times into our estimates because hospital identifiers are reassigned

Table 1 Baseline Characteristics of US Hospitals in 2018

Variable	Overall	EEG-incapable Hospital	EEG-capable Hospital	*p* Value	Predicted probability of EEG capability[a]
N (%)	4,550	3,309 (72.7)	1,241 (27.3)		
Bed size, n (%)				<0.001	
Small	2,405 (52.9)	2,077 (62.8)	328 (26.4)		14.3%
Medium	1,091 (24.0)	686 (20.7)	405 (32.6)		34.0%
Large	1,054 (23.2)	546 (16.5)	508 (40.9)		48.3%
Region, n (%)				<0.001	
Northeast	567 (12.5)	352 (10.6)	215 (17.3)		28.5%
Midwest	1,369 (30.1)	1,135 (34.3)	234 (18.9)		22.1%
South	1,754 (38.5)	1,253 (37.9)	501 (40.4)		29.3%
West	860 (18.9)	569 (17.2)	291 (23.4)		28.5%
Urbanicity, n (%)				<0.001	
Rural	1,659 (36.5)	1,606 (48.5)	53 (4.3)		7.4%
Urban	2,891 (63.5)	1,703 (51.5)	1,188 (95.7)		34.1%
Ownership, n (%)				<0.001	
Government, nonfederal	883 (19.4)	762 (23.0)	121 (9.8)		23.8%
Private, not-for-profit	2,893 (63.6)	2,014 (60.9)	879 (70.8)		27.0%
Private, investor-own	774 (17.0)	533 (16.1)	241 (19.4)		30.0%
Teaching status, n (%)				<0.001	
Nonteaching hospital	2,932 (64.4)	2,582 (78.0)	350 (28.2)		16.5%
Teaching hospital	1,618 (35.6)	727 (22.0)	891 (71.8)		39.2%

[a] Predicated probability of a hospital having EEG capability estimated as marginal effects holding all other hospital characteristics at their mean values.

each year in the NIS, which prevents tracking hospitals across years.

We determined the proportion of patients with SE who were admitted to EEG-capable and EEG-incapable hospitals and then compared differences in patient characteristics across these 2 groups from 2012 to 2018 using Pearson χ^2 tests for categorical and binary data and *t* tests for continuous data. We repeated this comparison for patients hospitalized with SE in 2018 to examine whether recent increased availability of inpatient EEG would change differences in the characteristics of patients admitted to EEG-capable and EEG-incapable hospitals. To better quantify variability in the use of EEG monitoring among those hospitalized at EEG-capable hospitals, we calculated the proportion of patients with SE who underwent EEG monitoring within each hospital and calculated the shrunken mean proportion using a mixed-effect logistic regression model.

To test our primary hypothesis, we fit multivariable fixed-effects logistic regression models to determine whether admission to an EEG-incapable hospital was associated with an increased likelihood of interhospital transfer. We fit generalized linear models specifying the binomial family and logit link function to match our dichotomous outcome of whether someone was transferred. We calculated exponentiated coefficients to estimate the risk ratio and adjusted for patient and hospital characteristics by including these variables as fixed effects to address the possible confounding at both levels. Adjusted patient characteristics included age, sex, race, primary expected payer, median household income, comorbidity severity, and intubation status. Adjusted hospital characteristics included hospital bed size, region, urban/rural status, hospital ownership, and teaching status. We stratified the primary analysis by urban and rural subgroups to examine whether the relationship between EEG capability and transfer differed by geographic setting. We also stratified the analysis by intubation status and comorbidity severity to examine whether the relationship between EEG capability and transfer differed by medical complexity because patients who are critically ill may warrant transfer for reasons unrelated to EEG access. We then repeated the multivariable fixed-effects logistic regression models to determine whether continuous EEG alone or routine EEG alone was associated

Table 2 Baseline Characteristics of Patients With Status Epilepticus, 2012–2018

Variable	Overall	EEG-incapable Hospital	EEG-capable Hospital	*p* Value
N[a] (%)	130,580	49,855 (38.2)	80,725 (61.8)	
Age, mean (SD)	52.0 (18.7)	51.9 (18.5)	52.1 (18.8)	0.345
Female, n (%)	60,525 (46.4)	23,000 (41.6)	37,525 (46.5)	0.574
Race, n (%)				<0.001
White	67,834 (53.7)	27,310 (57.0)	40,525 (51.7)	
Black	35,690 (28.3)	12,715 (26.5)	22,975 (29.3)	
Hispanic	15,850 (12.5)	5,460 (11.4)	10,390 (13.3)	
Asian or Pacific	2,200 (1.7)	815 (1.7)	1,385 (1.8)	
Native American	1,090 (0.9)	485 (1.0)	605 (0.8)	
Other	3,670 (2.9)	1,155 (2.4)	2,515 (3.2)	
Primary expected payer, n (%)				0.002
Medicare	58,519 (44.9)	22,875 (46.0)	35,645 (44.2)	
Medicaid	35,125 (27.0)	13,385 (26.9)	21,740 (27.0)	
Private insurance	22,715 (17.4)	8,180 (16.4)	14,535 (18.0)	
Self-pay	8,985 (6.9)	3,465 (7.0)	5,520 (6.8)	
No charge	755 (0.6)	215 (0.4)	540 (0.7)	
Other	4,225 (3.2)	1,620 (3.3)	2,605 (3.2)	
Median household income, n (%)				<0.001
Quartile 1	45,690 (35.9)	17,725 (36.3)	27,965 (35.6)	
Quartile 2	31,635 (24.8)	12,870 (26.4)	18,765 (23.9)	
Quartile 3	28,185 (22.1)	10,440 (21.4)	17,745 (22.6)	
Quartile 4	21,870 (17.2)	7,730 (15.9)	14,140 (18.0)	
Charlson comorbidity index, n (%)				<0.001
None (score 0)	58,055 (44.5)	23,070 (46.3)	34,985 (43.3)	
Mild (score 1–2)	45,590 (34.9)	17,055 (34.2)	28,535 (35.3)	
Moderate (score 3–4)	16,410 (12.6)	6,060 (12.2)	10,350 (12.8)	
Severe (score ≥5)	10,525 (8.1)	3,670 (7.4)	6,855 (8.5)	
Intubation, n (%)	48,940 (37.5)	16,820 (33.7)	32,120 (39.8)	<0.001
Received EEG, n (%)	16,210 (12.4)	0 (0)	16,210 (20.1)	<0.001

[a] N is a weighted count.

with an increased likelihood of transfer. An example of the regression output for our logit model is summarized in eTable 2 in the Supplement, links.lww.com/CPJ/A407.

To better characterize the relationship between EEG availability and interhospital transfer, we performed a secondary analysis estimating the association between EEG volume and likelihood of interhospital transfer. Among patients hospitalized with SE at an EEG-capable hospital, we fit multivariable fixed-effects logistic regression models to determine whether quintile of EEG volume was associated with likelihood of interhospital transfer adjusting for both patient and hospital characteristics similar to our primary analysis.

To ensure our findings were robust to different ways of defining an EEG-capable hospital, we calculated the proportion of hospitals that would be EEG capable and the proportion of patients hospitalized with SE at EEG-capable

Table 3 Likelihood of Patient Interhospital Transfer (RR) Based on Hospital EEG Capability, 2012–2018

	Urbanicity			Intubation status			Charlson comorbidity group		
Model	**Overall**	**Rural**	**Urban**	**Intubated**	**Not Intubated**	**None**	**Mild**	**Moderate**	**Severe**
Composite EEG (continuous and routine EEG)									
Unadjusted									
N	26,101	1,517	24,584	9,781	16,320	11,597	9,118	3,282	2,104
EEG-capable hospital	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
EEG-incapable hospital	1.85 (1.67, 2.04)	1.13 (0.81, 1.57)	1.70 (1.52, 1.89)	1.88 (1.63, 2.16)	1.96 (1.69, 2.26)	1.98 (1.69, 2.31)	1.85 (1.56, 2.20)	1.53 (1.18, 1.97)	1.95 (1.41, 2.69)
Patient and hospital adjusted									
N	24,590	1,375	23,043	9,192	15,312	10,830	8,605	3,108	1,971
EEG-capable hospital	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
EEG-incapable hospital	1.22 (1.09, 1.37)	1.10 (0.77, 1.58)	1.23 (1.09, 1.38)	1.28 (1.10, 1.49)	1.36 (1.16, 1.60)	1.36 (1.14, 1.63)	1.26 (1.05, 1.52)	1.19 (0.90, 1.59)	1.66 (1.16, 2.38)
Continuous EEG									
Unadjusted									
N	26,101	1,517	24,584	9,781	16,320	11,597	9,118	3,282	2,104
cEEG-capable hospital	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
cEEG-incapable hospital	2.18 (1.94, 2.45)	2.55 (1.17, 5.60)	1.96 (1.74, 2.12)	2.18 (1.87, 2.54)	2.37 (1.99, 2.82)	2.47 (2.05, 2.99)	2.33 (1.62, 3.34)	2.17 (1.62, 2.90)	2.33 (1.62, 3.34)
Patient and hospital adjusted									
N	24,590	1,375	23,043	9,192	15,312	10,830	8,605	3,108	1,971
cEEG-capable hospital	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
cEEG-incapable hospital	1.40 (1.23, 1.59)	3.06 (1.29, 7.25)	1.36 (1.18, 1.55)	1.39 (1.17, 1.66)	1.58 (1.30, 1.92)	1.67 (1.35, 2.07)	1.13 (0.92, 1.39)	1.68 (1.20, 2.33)	2.07 (1.39, 3.07)
Routine EEG									
Unadjusted									
N	26,101	1,517	24,584	9,781	16,320	11,597	9,118	3,282	2,104
rEEG-capable hospital	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
rEEG-incapable hospital	1.67 (1.51, 1.85)	1.01 (0.72, 1.42)	1.55 (1.39, 1.73)	1.74 (1.51, 2.01)	1.71 (1.48, 1.99)	1.75 (1.49, 2.06)	1.67 (1.40, 1.99)	1.43 (1.11, 1.85)	1.87 (1.34, 2.61)

Continued

Table 3 Likelihood of Patient Interhospital Transfer (RR) Based on Hospital EEG Capability, 2012–2018 *(continued)*

Model	Urbanicity			Intubation status			Charlson comorbidity group		
	Overall	Rural	Urban	Intubated	Not Intubated	None	Mild	Moderate	Severe
Patient and hospital adjusted									
N	24,590	1,375	23,043	9,192	15,312	10,830	8,605	3,108	1,971
rEEG-capable hospital	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
rEEG-incapable hospital	1.17 (1.05, 1.31)	0.99 (0.68, 1.44)	1.18 (1.05, 1.33)	1.25 (1.07, 1.45)	1.25 (1.06, 1.47)	1.26 (1.05, 1.50)	1.23 (1.02, 1.48)	1.17 (0.89, 1.55)	1.58 (1.11, 2.26)

Note: Urbanicity, intubation status, and Charlson comorbidity group omitted from respective stratification.
cEEG: continuous EEG, rEEG: routine EEG, RR: relative risk.

hospitals with the 2 alternate definitions accounting for imperfect sensitivity of our definition. We determined the sensitivity and specificity of our definition for EEG capability by repeating our primary regression model using the narrow and broad definitions of EEG-capable hospital described earlier.

All patient hospitalization analyses used the designated NIS survey weights to obtain nationally representative estimates. All analyses were performed using Stata 17.0.

Standard Protocol Approvals, Registrations, and Patient Consents

This study was approved by the institutional review board of University of California, San Francisco, and was exempt from the need for informed consent.

Data Availability

Data that support the findings of this study may be requested from the AHRQ.

Results

Annual Trends

From 2012 to 2018, the median annual proportion of hospitals that were EEG capable was 23.7%, increasing from 20.4% (n = 893/4,378) in 2012 to 27.3% (n = 1,241/4,550) in 2018 (M-K test $p < 0.001$). If the definition of EEG capability using ICD coding had sensitivity of 70% for identifying the actual availability of inpatient EEG, then 532 of the 4,550 hospitals included in the NIS in 2018 would have been misclassified as EEG incapable and the corrected proportion would be 39.0% (eTable 1B, links.lww.com/CPJ/A407 in the Supplement). The proportion of hospitals that were cEEG capable increased from 9.3% (n = 382/4,088) in 2012 to 22.5% (n = 931/4,136) in 2018.

Across all years, the proportion of EEG-capable hospitals that were located in urban settings was greater than 90%. In urban settings, the proportion of hospitals that were EEG capable increased from 30.5% (n = 826/2,712) in 2012 to 41.1% (n = 1,188/2,891) in 2018 (M-K test $p < 0.001$) (Figure). Conversely, in rural settings, the proportion of hospitals that were EEG capable decreased from 4.0% (n = 67/1,666) in 2012 to 3.2% (n = 53/1,659) in 2018 (M-K test $p = 0.002$). Again, accounting for the possibility that the definition of EEG capability using ICD coding had sensitivity of 70%, the corrected proportion of hospitals that were EEG capable in 2018 would have been 58.7% in urban settings and 4.6% in rural settings (eTable 1B, links.lww.com/CPJ/A407 in the Supplement).

Hospital Characteristics

EEG-capable hospitals were more likely to be large, located in urban settings, and teaching hospitals, while they were less likely to be located in the Midwest or government owned

Table 4 Likelihood of Patient Interhospital Transfer (RR) Based on EEG Volume, 2012–2018

EEG volume	No. of patient hospitalizations	Proportion of hospitalizations with EEG (%)	Primary		Sensitivity (restricting to quintiles 1–4)	
			Unadjusted RR	Adjusted RR[a]	Unadjusted RR	Adjusted RR[a]
N			16,136	15,021	11,396	10,572
Quintile 1	13,160	3.8	2.97 (2.32, 3.79)	2.20 (1.65, 2.93)	1.59 (1.28, 1.98)	1.36 (1.08, 1.70)
Quintile 2	14,740	5.5	2.50 (1.95, 3.21)	1.84 (1.39, 2.44)	1.34 (1.07, 1.68)	1.13 (0.90, 1.41)
Quintile 3	10,880	9.0	2.44 (1.87, 3.19)	1.99 (1.48, 2.66)	1.31 (1.03, 1.67)	1.21 (0.95, 1.55)
Quintile 4	18,220	18.2	1.87 (1.45, 2.40)	1.64 (1.24, 2.16)	Ref	Ref
Quintile 5	23,725	44.8	Ref	Ref	—	—

Abbreviation: RR = relative risk.
[a] Adjusted for patient-level and hospital-level characteristics.

(Table 1). After adjustment for other hospital characteristics, the predicted probability that a hospital would be EEG capable was more than 4 times higher in urban when compared with that in rural settings (7.4% among rural hospitals vs 34.1% among urban hospitals) and more than 3 times higher in large when compared with that in small hospitals (14.3% among small hospitals, 34.0% among medium hospitals, and 48.3% among large hospitals).

Patient Hospitalization Characteristics

Among 130,580 hospitalizations for SE, 49,855 (38.2%) occurred at EEG-incapable hospitals and 80,725 (61.8%) occurred at EEG-capable hospitals. Patients admitted to EEG-capable hospitals with SE were less likely White and more likely to be privately insured, have higher income, have more medical comorbidities, and undergo intubation (Table 2). Restricting the analysis to hospitalizations that occurred in 2018 did not demonstrate meaningful differences in the proportion of hospitalizations at EEG-capable hospitals or characteristics among patients at both hospital types (eTable 3 in the Supplement, links.lww.com/CPJ/A407).

Among those admitted to an EEG-capable hospital, the overall proportion of patients with SE who underwent EEG monitoring during their hospitalization was 20.1%, while the shrunken mean proportion was 51.1% (SD 27.1%) and varied across hospitals with the proportion of patients who underwent EEG monitoring ranging from 7.6% to 97.8%.

Interhospital Transfers

The overall proportion of hospitalizations from 2012 to 2018 during which admission resulted in interhospital transfer was 5.5%. The transfer rates for hospitalizations at EEG-incapable hospitals (7.7%) and cEEG-incapable hospitals (7.2%) were similar. Among EEG-capable hospitals, 4.1% of patients were transferred compared with 3.3% of patients hospitalized at cEEG-capable hospitals and transferred.

After adjustment, admission to an EEG-incapable hospital was associated with a 22% increased likelihood of interhospital transfer (adjusted RR 1.22, [95% CI, 1.09–1.37]; $p < 0.001$) (Table 3). The association was unchanged for urban hospitals and after stratifying hospitalizations by intubation status and comorbidity severity. The association was not present in the 1,517 hospitalizations at rural hospitals. We found the relative risks and odds ratios to be close approximations (eTable 4 in the Supplement, links.lww.com/CPJ/A407).

Repeating the analysis to examine whether admission to a hospital that specifically did not code for cEEG demonstrated that lack of cEEG capability was associated with a 40% increased likelihood of interhospital transfer (adjusted RR 1.40, [95% CI, 1.23–1.59, $p < 0.001$) (Table 3). Unlike the composite exposure describing whether a hospital was capable of any type of EEG (routine or continuous), the association between cEEG capability and interhospital transfer was seen within rural hospital where lack of cEEG was associated with triple the likelihood of interhospital transfer (adjusted RR 3.06, [95% CI, 1.29–7.25, $p < 0.001$). Similar to the composite exposure, lack of cEEG was also associated with interhospital transfer for those admitted to urban hospitals and after stratifying by intubation status and comorbidity severity.

Among EEG-capable hospitals, admission to hospitals with a lower volume of EEG (defined as quintile 1) was also associated with an increased likelihood of interhospital transfer. Patients with SE admitted to hospitals in the lowest quintile were more than 2 times more likely to undergo interhospital transfer (adjusted RR 2.22, [95% CI 1.65–2.93]; $p < 0.001$) (Table 4).

Sensitivity Analyses

Repeating the analyses using both the narrow and broad definitions of EEG capability resulted in minor changes to the findings. Using data from 2018, the proportion of hospitals that met the narrow definition for EEG capability was 12.8% (eTables 5–7 in the Supplement, links.lww.com/CPJ/A407) and the proportion of hospitals that met the broad definition for EEG capability was 31.8% (eTables 8–10, links.lww.com/CPJ/A407). The proportion of patients hospitalized with SE who were admitted to an EEG-capable hospital decreased to 37.2% using the narrow definition and increased to 68.6% using the broad definition. Comparisons of hospital and patient baseline characterizations were similar, and admission to an EEG-incapable hospital remained associated with interhospital transfer using both definitions.

Discussion

In this national study of inpatient EEG among US hospitals, we found that, as of 2018, approximately 28% of patients with SE were admitted to hospitals that did not have documented EEG capability. Surprisingly, within EEG-capable hospitals, the probability of receiving an EEG ranged widely from 8% to 98%. These practice patterns highlight the large variability in the utilization of inpatient EEG services in spite of guideline recommendations.

We were unable to determine the cause of variable EEG use in EEG-capable hospitals. This could reflect differing clinical practices between physicians because there is uncertainty about who needs EEG monitoring. It may also reflect inconsistent availability of EEG monitoring during weekends or evenings.[19,20] Future studies should be aimed at understanding the barriers and variability of EEG use in EEG-capable hospitals and present an important opportunity to determine whether consistent use of EEG is indeed associated with improved clinical outcomes.

We found that approximately 73% of US hospitals lacked EEG capability during this study. In 2018, approximately 78% of hospitals lacked cEEG. There is limited literature that evaluates access to inpatient EEG nationally and describes geographic differences in access. However, we relied on ICD coding to identify the use of inpatient EEG. ICD codes are imperfectly sensitive and thus may not reliably capture inpatient EEG availability, which would misclassify hospitals and suggest they lack EEG capability when EEG is in fact available. Accounting for the possibility that ICD coding is 70% sensitive, the proportion of hospitals that lack EEG capability would instead be 40% in urban settings and 95% in rural settings. And, importantly, most patients hospitalized with SE were admitted to hospitals that were in fact EEG capable. Identifying which patients with SE are most likely to be hospitalized at an EEG-incapable hospital despite needing urgent EEG can help focus future interventions to improve healthcare access.

Our finding that the proportion of hospitals with EEG capability is 55% lower in rural when compared with urban settings and that hospitals in the Midwest are also less likely to be EEG capable suggest there are geographic differences in access to specialized inpatient epilepsy care that are similar to those found for outpatient epilepsy care and specialized care for other neurologic conditions.[21-25] In addition to geographic inequities, future studies investigating majority-minority hospital differences in access to inpatient EEG represents an important next step in identifying neurologic healthcare inequities.

We focused this study on interhospital transfer because this is common among patients hospitalized with seizure and the data set did not provide information about clinical outcomes among those who underwent transfer. Indeed, we found that 5.5% of patients with SE undergo interhospital transfer, which reflects other studies that show incidence of transfer is generally greater than 5% and higher than the general hospitalized population for which the proportion of patients transferred is closer to 1.5%.[4,5] The increased incidence of interhospital transfers among patients with SE demonstrates the importance of this aspect of care for patients with seizure and the need for further understanding of the factors driving transfer and whether transfer is affecting clinical outcomes.

Admission to an EEG-incapable hospital was associated with a 22% increased risk of interhospital transfer compared with admission to a cEEG-incapable hospital which was associated with a 40% increased likelihood. This was true regardless of medical complexity and whether the patient had undergone intubation. We were unable to determine the reason for interhospital transfer and thus could not confirm whether EEG access was a proximate explanation for the decision. Hospitals with EEG capability will typically have access to a neurologist to read the EEG recording and potentially consult on care. Hospital EEG capability is also likely associated with the availability of other diagnostic tools and therapies that patients who undergo interhospital transfer may require. This analysis was unable to determine whether it was absence of EEG equipment, inpatient neurologic expertise, or another associated factor that contributed to likelihood of interhospital transfer. However, hospital EEG capability is certainly 1 potential driver of transfer. It represents the only method for evaluating possible nonconvulsive SE in patients with persistent encephalopathy. And prior studies suggest increasing access to inpatient EEG does in fact lower rates of transfer. In a single-center community hospital study, implementation of local EEG infrastructure was associated with 58% lower incidence of interhospital transfer to the affiliated academic center.[9] In a separate community hospital, local adoption of point-of-care EEG was associated with 94% fewer potential interhospital transfers.[26] Even among hospitals with EEG capability, more frequent EEG use was associated with fewer transfers, further suggesting the association between consistent EEG access and transfer.

Interhospital transfers remain a key aspect of our US healthcare infrastructure to ensure specialized higher level of care is available to all patients. While some interhospital transfers may be clinically warranted for specialized resources not locally available, some transfers may be avoidable. Given the general lack of widespread EEG capability and the frequency of interhospital transfer among patients hospitalized with SE, it is important to determine whether a more intentional system for inpatient epilepsy care would improve patient outcomes and lower costs. Having EEG capability is likely not cost-effective for all hospitals, particularly those that are small or the need for EEG is infrequent because they do not have the finances to ensure availability of technology, trained personnel, and real-time monitoring.[19,27] To address this, it may be possible to identify patients who can be safely managed without inpatient EEG or determine a system to more appropriately triage patients to hospitals with and without EEG capability by Emergency Medical Services in the field before hospital arrival. It may also be important to encourage the use of new types of EEG that are easier and more cost-effective for small hospitals to implement because they do not require hiring a trained technologist.[26,28] Alternatively, we may need to formalize other care models such as telemedicine or the hub-and-spoke models used for stroke. Regardless of the solution, our study suggests that many patients with SE are admitted to hospitals that lack EEG capability and subsequently transferred; thus, the health system may benefit from more standardized guidelines to organize care for patients with SE.

The study has limitations to consider. First, using ICD codes to determine EEG capability has been previously performed but likely underestimates EEG capability.[14,29-31] To account for this, we report estimates corrected for reduced sensitivity and repeated our analysis with a more sensitive definition of EEG capable, which led to similar results. Second, there is potential for residual confounding. Patients with more severe seizures may be more likely admitted to EEG-capable hospitals and more likely transferred. Our models did not include this information; however, this would bias our results to the null.[32-34] We also reported estimates stratified by medical complexity. Third, the NIS data set represents a sample of discharges at each included hospital. The lower number of discharges included per hospital may lead to higher variance and sampling error in our hospital-level estimates. Fourth, our analysis captures only patients who presented to an ED and were admitted to the same hospital. We do not include patients who were transferred directly from an ED setting, which is likely a large proportion of patients with SE who undergo interfacility transfer. Thus, our findings likely underestimate both patients with SE presenting to facilities without EEG capabilities and patients with SE who undergo interfacility transfers. Last, the inability to link patients across hospitalizations in the NIS data set prevents the understanding of total length of stay. Future analysis of total length of stay in the transfer population may provide insight on the observed wide variability of EEG use.

Nationally, a plurality of hospitals lack EEG capability yet provide care to a large proportion of patients hospitalized with SE. Despite having access to EEG, we found wide variability in the use of EEG among EEG-capable hospitals. Our results suggest lack of inpatient EEG may contribute to interhospital transfer, but the overall impact of the constrained access to inpatient EEG is unclear. Given the frequency of SE and its associated morbidity, it is important to understand whether improving EEG utilization among EEG-capable hospitals and availability of inpatient EEG among EEG-incapable hospitals can improve outcomes and decrease costs to the health system.

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Appendix (continued)

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