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Rural-Urban Disparities in Epilepsy Outcomes in the United States

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Abstract

Background and Objectives

Rural residence is linked to poor access to neurologists and specialized epilepsy centers, yet its impact on clinical epilepsy outcomes remains unclear. To address this knowledge gap, we assessed the association between rurality and epilepsy outcomes in a nationally representative cohort in the United States.

Methods

We conducted a retrospective cohort study using the National Inpatient Sample (2016–2021), including patients with a primary diagnosis of epilepsy and recurrent seizures. The primary exposure was patient rurality, defined using the National Center for Health Statistics Urban-Rural Classification Scheme for Counties. Logistic regression models were used to study the effect of rurality on in-hospital mortality, presenting in status epilepticus, prolonged length of stay, nonroutine discharge, and receipt of EEG. Models were adjusted for demographic, socioeconomic, and hospital-related characteristics and Elixhauser comorbidities. Subanalyses examined patients presenting in status epilepticus, those with private insurance, and those admitted to urban teaching hospitals.

Results

A total of 841,445 epilepsy admissions were included (median age 56 years, 47.2% female). After adjusting for covariates, patients from the most rural counties experienced significantly higher odds of in-hospital mortality (odds ratio [OR] 1.93 [95% CI 1.56–2.39], $p < 0.001$), presenting in status epilepticus (OR 1.32 [95% CI 1.24–1.41], $p < 0.001$), and prolonged length of stay (OR 1.29 [95% CI 1.19–1.41], $p < 0.001$), relative to patients from the most urban counties. The most rural patients also experienced lower odds of receiving EEG (OR 0.88 [95% CI 0.77–1.00], $p = 0.047$) and nonroutine discharge (OR 0.90 [95% CI 0.85–0.96], $p = 0.001$). When subanalyzing only patients with private insurance, the associations between rurality and mortality, presenting in status epilepticus, and prolonged length of stay were no longer observed.

Discussion

Increasing rurality was associated with markedly worse epilepsy outcomes, including nearly double the odds of in-hospital mortality. The attenuation of these disparities among privately insured patients suggests that modifiable structural barriers drive rural-urban disparities, rather than geography alone. Inherent to observational studies, residual confounding and limited clinical granularity remain important considerations. These findings underscore the urgent need for targeted public health interventions to improve outcomes for rural epilepsy populations.

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Glossary

HCUP = Healthcare Cost and Utilization Project; **ICD-10-CM** = International Classification of Diseases-Tenth Edition-Clinical Modification; **IQR** = interquartile range; **NCHS** = National Center for Health Statistics; **NIS** = National Inpatient Sample; **OR** = odds ratio.

Introduction

Epilepsy is one of the most prevalent neurologic disorders, affecting nearly 3 million adults in the United States alone.[1,2] Despite advancements in epilepsy diagnosis and treatment, numerous disparities in epilepsy care persist.[3-5] Previous studies have found that increasing rurality is associated with reduced access to EEG[6] and epilepsy centers.[7] However, the extent to which rurality affects epilepsy outcomes remains underexplored.

It is well documented that increasing rurality is associated with higher mortality rates and shortened life expectancy in the United States.[8-10] Epilepsy is a complex chronic condition, often requiring specialized neurologic care,[11] timely diagnosis,[12] and consistent access to antiseizure medications.[13,14] Furthermore, delayed intervention in status epilepticus can critically affect outcomes.[15] However, for people with epilepsy residing in rural geographic locations, these needs may be more difficult to meet. Critically, people with epilepsy may face barriers in access to neurologists, epilepsy specialists, diagnostic services, and surgical procedures.[16-18]

Nevertheless, the association between increasing rurality and epilepsy-related mortality remains unclear. Given that people with epilepsy have a substantially increased risk of premature death,[19] it is crucial to understand the impact of rurality on epilepsy outcomes to optimize targeted public health interventions. To address this knowledge gap, we performed a nationwide retrospective cohort study to investigate the relationship between rurality and outcomes in epilepsy.

Methods

Standard Protocol Approvals, Registrations, and Patient Consents

This study used the National Inpatient Sample (NIS), a database of inpatient hospital admissions in the United States, and part of the Healthcare Cost and Utilization Project (HCUP).[20] The analyses presented here were performed in keeping with the HCUP Data Use Agreement. The NIS is a publicly available limited data set containing no direct patient identifiers: therefore, as specified by the HCUP Data Use Agreement, no ethical approval or written informed consent is required.[20] This study follows the Strengthening the Reporting of Observational Studies in Epidemiology guidelines.[21]

Data Source, Inclusion Criteria, and Covariates

We performed a retrospective cohort study using the 2016–2021 NIS data sets. The NIS contains data from a national sample of approximately 7 million hospital admissions annually; by applying sampling weights, the NIS can be used to provide national estimates of approximately 35 million annual admissions.[20] Using International Classification of Diseases-Tenth Edition-Clinical Modification (ICD-10-CM) codes, cases were included if they had a primary diagnosis of epilepsy and recurrent seizures (G40.x). Patients admitted electively or younger than 18 years were excluded (Figure 1).

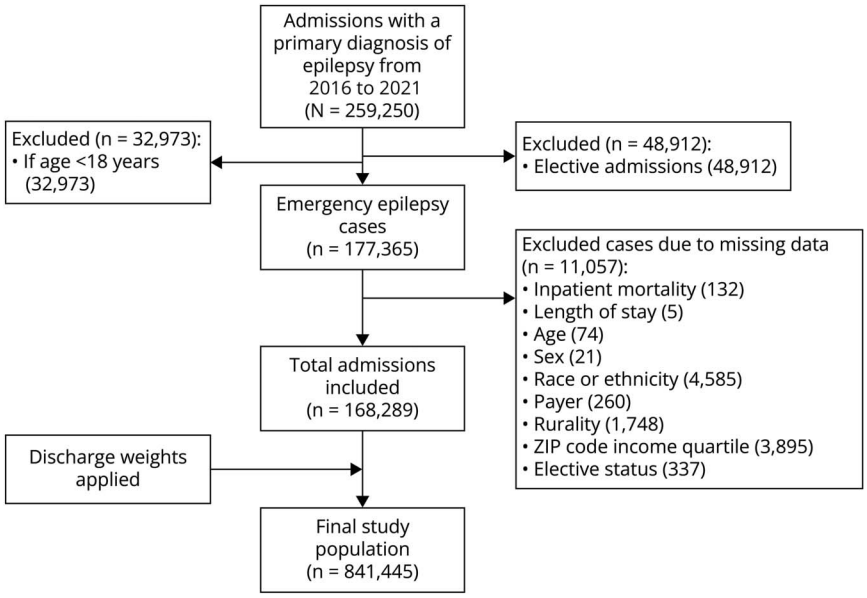
The primary exposure of interest was patient rurality (county of residence), defined using the National Center for Health Statistics (NCHS) Urban-Rural Classification Scheme for Counties.[22] This classification categorizes counties based on their metropolitan status and population size. Counties were assigned to an ordinal scale from 1 (most urban) to 6 (most rural): (1) large central metropolitan, (2) large fringe metropolitan, (3) medium metropolitan, (4) small metropolitan, (5) micropolitan, and (6) noncore.

The following additional variables were extracted: age, sex (dichotomous classification of male or female), race or ethnicity, primary expected payer, smoking status (ICD-10-CM codes F17.210, F17.211, F17.213, F17.218, F17.219), Elixhauser comorbidities, hospital size (bed count), hospital teaching status, hospital control/ownership, census region of hospital, and median household income quartile for patients' ZIP code. In the NIS, race and ethnicity are collapsed into a single variable with the following categories: White, Black, Hispanic, Asian or Pacific Islander, Native American, and Other. Notably, demographic data in the NIS are provided by hospitals, and therefore, exact reporting practices may vary: for example, whether variables are self-reported or provider-assigned. This is particularly relevant to race/ethnicity, where individuals might occupy more than one category, and it is not clear under what circumstances individuals are categorized as "Other." Furthermore, where individuals are categorized as both Hispanic and a separate racial category by a hospital, Hispanic takes precedence in the NIS: for example, an individual categorized as both Black and Hispanic would be assigned a value of "Hispanic." Elixhauser comorbidities, a well-validated standardized set of diagnoses used for comorbidity adjustment, were calculated using the *elixhauser* Stata command based on ICD-10-CM codes.[23,24]

Outcome Measures

Inpatient mortality was the primary outcome. The following additional outcomes were analyzed: odds of presenting in status epilepticus, prolonged length of stay (>7 days admission), nonroutine discharge (discharge to any destination other than home or self-care; specifically, any value other than

Figure 1 Flowchart of Cohort Selection from the National Inpatient Sample



After exclusions and application of discharge sampling weights, the final cohort was representative of 841,445 epilepsy admissions.

1 for the "DISP" NIS variable), and odds of receiving EEG (ICD-10 Procedure Coding System codes: 4A00X4Z or 4A10X4Z).

Handling of Missing Data

All variables had <5% missingness and were handled using complete case analysis (Figure 1).[25,26]

Statistical Analysis

Statistical analyses were performed using Stata 18.0/MP (StataCorp LLC, College Station, TX). For univariate statistics, categorical variables were compared across rurality levels using omnibus χ^2 tests while continuous variables were analyzed using univariate linear regression.

Multivariable logistic regression models were built to study the independent effect of rurality on in-hospital mortality, presenting in status epilepticus, prolonged length of stay, nonroutine discharge, and odds of receiving EEG. All models adjusted for age, race or ethnicity, primary expected payer, smoking status, Elixhauser comorbidities, hospital size (bed count), hospital teaching status, hospital control/ownership, census region of hospital, median household income quartile for patients' ZIP code, and rurality. We also performed subanalyses limited to the following subgroups: patients diagnosed with status epilepticus (G40x.1), patients with private insurance, and patients admitted to urban teaching hospitals. Because significant differences in the racial/ethnic distribution across levels of rurality were observed on univariate analysis, we assessed for a race/ethnicity-rurality interaction through inclusion of an interaction term in the primary mortality model. Evidence of interaction was evaluated using a global Wald test across categorical levels of race/ethnicity and rurality, with a p value of <0.05 indicating evidence of significant interaction. Additional exploratory subanalyses were performed to examine whether epilepsy etiology modified the association between rurality and the primary outcome of in-hospital mortality. Because the primary code G40.x does not indicate the cause of epilepsy, etiology subgroups were defined using secondary ICD-10 diagnoses consistent with distinct epilepsy etiologies, including poststroke epilepsy (I69.x) and tumor-associated epilepsy (C71.x, D33.x, D43.x, D49.6, C79.31).

Rurality was analyzed both categorically (reference: first level of NCHS Urban-Rural Classification) and continuously to estimate linear trend.[27,28] Rurality p values for trend were calculated by including rurality as a continuous variable in logistic regression models. The assumption of a linear relationship between continuous rurality and log odds of the outcome was verified using the Box-Tidwell test, with a p value of <0.05 indicating significant nonlinearity; where this assumption was violated in the primary analysis for a given outcome, trend analyses were not reported for subanalyses of that outcome. Trend analyses assume equal spacing between levels of rurality, an assumption that may not strictly hold; accordingly, results should be interpreted as reflecting overall trends rather than differences between adjacent categories.

Forest plots were generated using MATLAB R2024b (MathWorks, Natick, MA).

Data Availability

In keeping with the HCUP Data Use Agreement, sharing of the data used in this study is not permitted.

Results

Population Characteristics

The analysis provided estimates for 841,445 epilepsy admissions after exclusions (Figure 1). Table 1 lists cohort characteristics (eTable 1 provides full cohort comorbidity characteristics). The median age was 56 years (interquartile range [IQR] = 39–68), with patients from the most rural counties older than those from the most urban counties (most rural median [IQR] = 58 [42–70] vs most urban median [IQR] = 55 [37–67], $p < 0.001$). Overall, 47.2% of patients were female, which varied across rurality levels (most rural 48.3% vs most urban 45.8%, $p < 0.001$).

Significant racial/ethnic differences were observed across rurality levels ($p < 0.001$). In the most rural counties, 76.5% of patients were White, 16.0% Black, and 3.1% Hispanic. By contrast, the most urban counties had lower proportions of White patients (38.7%) and higher proportions of Black (36.2%) and Hispanic (17.3%) patients.

Insurance coverage also varied by rurality ($p < 0.001$). Compared with urban areas, patients in the most rural counties were more likely to have Medicare (most rural 52.0% vs most urban 42.9%) and less likely to have Medicaid (most rural 21.8% vs most urban 31.4%). Private insurance was less common in rural counties (most rural 16.3% vs most urban 16.9%). Moreover, patients from the most rural counties were significantly more likely to be in the lowest ZIP code income quartile compared with those in the most urban counties (most rural 66.7% vs most urban 39.7%, $p < 0.001$).

Hospital admissions predominantly occurred at urban teaching hospitals across all rurality levels (76.6%). Among the most rural patients, 59.0% were admitted to urban teaching hospitals compared with 30.4% at rural hospitals, which was lower than the 85.2% admitted to urban teaching hospitals in the most urban counties ($p < 0.001$). In addition, hospital admissions for the most rural counties were concentrated in the South (60.6%) and Midwest (24.6%), whereas admissions for the most urban counties were distributed across the South (30.9%), Northeast (23.5%), West (26.1%), and Midwest (19.5%) ($p < 0.001$).

Rurality and Epilepsy Outcomes

Multivariable logistic regression models were used to investigate the independent effect of rurality on epilepsy outcomes, with in-hospital mortality as the primary outcome. Secondary analyses evaluated the association between rurality and status epilepticus at presentation, prolonged length of stay, nonroutine discharge, and receipt of EEG.

For in-hospital mortality (Table 2A; Figure 2A), increasing rurality was associated with higher odds of mortality (odds ratio [OR] 1.16 [95% CI 1.12–1.20], p for trend <0.001). When analyzed categorically, patients from the most rural counties experienced 93% higher odds of in-hospital mortality compared with patients from the most urban counties (OR 1.93 [95% CI 1.56–2.39], $p < 0.001$). Subanalysis of patients presenting in status epilepticus (eTable 2A) revealed a similar association (OR 1.14 [95% CI 1.10–1.20], p for trend <0.001), with patients from the most rural counties experiencing 74% higher odds of in-hospital mortality than patients from the most urban counties (OR 1.74 [95% CI 1.32–2.29], $p < 0.001$), suggesting that the increased odds of mortality associated with rurality persist even in status epilepticus. Notably, in the subanalysis of patients with private insurance (eTable 3A), the association between rurality and mortality was no longer observed (OR 1.07 [95% CI 0.98–1.18], p for trend = 0.127), suggesting that access to private insurance is associated with attenuation of the rural-urban disparities in epilepsy mortality outcomes. In the subanalysis of patients admitted to urban teaching hospitals (eTable 4A), increasing rurality continued to be associated with increased mortality (OR 1.17 [95% CI 1.13–1.22], p for trend <0.001). No evidence of a significant race/ethnicity-rurality interaction was observed ($p = 0.530$). Exploratory subanalyses regarding epilepsy etiology (eTable 5) suggested that rurality was associated with increased mortality in post-stroke epilepsy (OR 1.18 [95% CI 1.07–1.30], p for trend = 0.001) but not tumor-associated epilepsy (OR 1.09 [95% CI 0.97–1.23], p for trend = 0.136).

For status epilepticus at presentation, increasing rurality was associated with higher odds of status epilepticus (OR 1.06 [95% CI 1.05–1.07], p for trend <0.001) (Table 2B; Figure 2B). When analyzed categorically, patients from the most rural counties experienced 32% higher odds of presenting in status epilepticus compared with patients from the most urban counties (OR 1.32 [95% CI 1.24–1.41], $p < 0.001$). In the subanalysis of patients with private insurance (eTable 3B), the association between rurality and presenting in status epilepticus was no longer observed (OR 1.27 [95% CI 0.98–1.63], p for trend = 0.068). In the subanalysis of patients admitted to urban teaching hospitals (eTable 4B), increasing rurality continued to be associated with higher odds of presenting in status epilepticus (OR 1.06 [95% CI 1.05–1.08], p for trend <0.001).

For prolonged length of stay, a test for trend was not performed because of evidence of nonlinearity. When analyzed categorically, patients from the most rural counties experienced 29% higher odds of a prolonged stay compared with patients from the most urban counties (OR 1.29 [95% CI 1.19–1.41], $p < 0.001$) (Table 2C; Figure 2C). Subanalysis of patients presenting in status epilepticus (eTable 2B) revealed a similar association, with patients from the most rural counties experiencing 22% higher odds of a prolonged stay compared with patients from the most urban counties (OR 1.22 [95% CI 1.07–1.39], $p = 0.002$). In the subanalysis of patients with private insurance (eTable 3C), patients from the most rural counties were no longer more likely to experience a prolonged length of stay (OR 0.90 [95% CI 0.72–1.12], $p = 0.336$). In the subanalysis of patients admitted to urban

Table 1 Cohort Characteristics for 841,445 Epilepsy Admissions From the NIS (2016–2021), Stratified by Rurality

	NCHS rurality level							
Variable	**1 (least rural)**	**2**	**3**	**4**	**5**	**6 (most rural)**	**Total**	***p* Value**
Cohort size, n (%)	295,620 (35.1)	204,750 (24.3)	170,085 (20.2)	71,400 (8.5)	59,260 (7.0)	40,330 (4.8)	841,445 (100.0)	
Age, y, median (IQR)	55 (37–67)	56 (39–69)	56 (39–68)	56 (40–69)	56 (40–69)	58 (42–70)	56 (39–68)	<0.001
Sex, n (%)								
Male	160,115 (54.2)	105,455 (51.5)	89,350 (52.5)	37,060 (51.9)	31,070 (52.4)	20,845 (51.7)	443,895 (52.8)	<0.001
Female	135,505 (45.8)	99,295 (48.5)	80,735 (47.5)	34,340 (48.1)	28,190 (47.6)	19,485 (48.3)	397,550 (47.2)	
Race or ethnicity, n (%)								
Asian or Pacific Islander	7,175 (2.4)	2,995 (1.5)	2,160 (1.3)	445 (0.6)	390 (0.7)	40 (0.1)	13,205 (1.6)	<0.001
Black	106,925 (36.2)	46,600 (22.8)	36,210 (21.3)	12,865 (18.0)	8,800 (14.8)	6,460 (16.0)	217,860 (25.9)	
Hispanic	51,150 (17.3)	16,375 (8.0)	18,870 (11.1)	4,205 (5.9)	2,750 (4.6)	1,250 (3.1)	94,600 (11.2)	
Native American	1,075 (0.4)	475 (0.2)	1,425 (0.8)	960 (1.3)	1,230 (2.1)	1,120 (2.8)	6,285 (0.7)	
Other	14,815 (5.0)	6,050 (3.0)	3,000 (1.8)	1,425 (2.0)	900 (1.5)	590 (1.5)	26,780 (3.2)	
White	114,480 (38.7)	132,255 (64.6)	108,420 (63.7)	51,500 (72.1)	45,190 (76.3)	30,870 (76.5)	482,715 (57.4)	
Insurance payer, n (%)								
Medicare	126,680 (42.9)	99,010 (48.4)	80,685 (47.4)	35,480 (49.7)	30,175 (50.9)	20,970 (52.0)	393,000 (46.7)	<0.001
Medicaid	92,940 (31.4)	43,220 (21.1)	41,160 (24.2)	16,475 (23.1)	13,185 (22.2)	8,805 (21.8)	215,785 (25.6)	
Private insurance	49,820 (16.9)	44,105 (21.5)	31,050 (18.3)	12,230 (17.1)	10,045 (17.0)	6,585 (16.3)	153,835 (18.3)	
Self-pay	17,965 (6.1)	11,255 (5.5)	10,435 (6.1)	4,075 (5.7)	3,515 (5.9)	2,480 (6.1)	49,725 (5.9)	
No charge	1,760 (0.6)	1,385 (0.7)	930 (0.5)	330 (0.5)	185 (0.3)	115 (0.3)	4,705 (0.6)	
Other	6,455 (2.2)	5,775 (2.8)	5,825 (3.4)	2,810 (3.9)	2,155 (3.6)	1,375 (3.4)	24,395 (2.9)	
ZIP code income quartile, n (%)								
1	117,420 (39.7)	31,500 (15.4)	64,855 (38.1)	28,290 (39.6)	32,005 (54.0)	26,920 (66.7)	300,990 (35.8)	<0.001
2	62,180 (21.0)	41,690 (20.4)	48,905 (28.8)	26,550 (37.2)	20,325 (34.3)	10,725 (26.6)	210,375 (25.0)	
3	63,270 (21.4)	57,740 (28.2)	39,340 (23.1)	14,080 (19.7)	6,155 (10.4)	2,460 (6.1)	183,045 (21.8)	
4	52,750 (17.8)	73,820 (36.1)	16,985 (10.0)	2,480 (3.5)	775 (1.3)	225 (0.6)	147,035 (17.5)	
Bed size of hospital, n (%)								
Small	50,245 (17.0)	46,110 (22.5)	25,770 (15.2)	14,425 (20.2)	4,805 (8.1)	6,180 (15.3)	147,535 (17.5)	<0.001
Medium	92,460 (31.3)	65,585 (32.0)	46,810 (27.5)	21,475 (30.1)	12,150 (20.5)	10,550 (26.2)	249,030 (29.6)	
Large	152,915 (51.7)	93,055 (45.4)	97,505 (57.3)	35,500 (49.7)	42,305 (71.4)	23,600 (58.5)	444,880 (52.9)	
Hospital location/ teaching status, n (%)								
Rural	325 (0.1)	735 (0.4)	1,120 (0.7)	970 (1.4)	26,870 (45.3)	12,255 (30.4)	42,275 (5.0)	<0.001
Urban nonteaching	43,330 (14.7)	47,990 (23.4)	34,060 (20.0)	21,240 (29.7)	3,845 (6.5)	4,295 (10.6)	154,760 (18.4)	
Urban teaching	251,965 (85.2)	156,025 (76.2)	134,905 (79.3)	49,190 (68.9)	28,545 (48.2)	23,780 (59.0)	644,410 (76.6)	

Continued

Table 1 Cohort Characteristics for 841,445 Epilepsy Admissions From the NIS (2016–2021), Stratified by Rurality *(continued)*

Variable	NCHS rurality level							
	1 (least rural)	2	3	4	5	6 (most rural)	Total	*p* Value
Hospital ownership, n (%)								
Government, nonfederal	35,585 (12.0)	16,120 (7.9)	21,800 (12.8)	8,305 (11.6)	10,140 (17.1)	7,275 (18.0)	99,225 (11.8)	<0.001
Private, not-for-profit	201,775 (68.3)	158,220 (77.3)	121,555 (71.5)	54,360 (76.1)	41,435 (69.9)	27,610 (68.5)	604,955 (71.9)	
Private, investor-owned	58,260 (19.7)	30,410 (14.9)	26,730 (15.7)	8,735 (12.2)	7,685 (13.0)	5,445 (13.5)	137,265 (16.3)	
Census region of hospital, n (%)								
Northeast	69,360 (23.5)	60,225 (29.4)	30,390 (17.9)	8,515 (11.9)	7,565 (12.8)	2,850 (7.1)	178,905 (21.3)	<0.001
Midwest	57,710 (19.5)	42,605 (20.8)	27,695 (16.3)	19,220 (26.9)	16,840 (28.4)	9,925 (24.6)	173,995 (20.7)	
South	91,425 (30.9)	81,490 (39.8)	81,810 (48.1)	31,825 (44.6)	28,245 (47.7)	24,450 (60.6)	339,245 (40.3)	
West	77,125 (26.1)	20,430 (10.0)	30,190 (17.7)	11,840 (16.6)	6,610 (11.2)	3,105 (7.7)	149,300 (17.7)	
In-hospital mortality, n (%)								
Survived	292,590 (99.0)	202,420 (98.9)	167,840 (98.7)	70,425 (98.6)	58,215 (98.2)	39,665 (98.4)	831,155 (98.8)	<0.001
Died	3,030 (1.0)	2,330 (1.1)	2,245 (1.3)	975 (1.4)	1,045 (1.8)	665 (1.6)	10,290 (1.2)	
Status epilepticus, n (%)								
No status epilepticus	231,640 (78.4)	161,040 (78.7)	129,660 (76.2)	55,060 (77.1)	45,730 (77.2)	30,845 (76.5)	653,975 (77.7)	<0.001
Status epilepticus	63,980 (21.6)	43,710 (21.3)	40,425 (23.8)	16,340 (22.9)	13,530 (22.8)	9,485 (23.5)	187,470 (22.3)	
Discharge disposition, n (%)								
Routine	172,810 (58.5)	118,110 (57.7)	99,665 (58.6)	42,500 (59.5)	34,245 (57.8)	23,515 (58.3)	490,845 (58.3)	0.014
Nonroutine	122,810 (41.5)	86,640 (42.3)	70,420 (41.4)	28,900 (40.5)	25,015 (42.2)	16,815 (41.7)	350,600 (41.7)	
Length of stay, n (%)								
≤7 d	257,145 (87.0)	178,150 (87.0)	147,385 (86.7)	62,340 (87.3)	51,605 (87.1)	34,855 (86.4)	731,480 (86.9)	0.371
>7 d	38,475 (13.0)	26,600 (13.0)	22,700 (13.3)	9,060 (12.7)	7,655 (12.9)	5,475 (13.6)	109,965 (13.1)	
EEG, n (%)								
No EEG	248,790 (84.2)	172,785 (84.4)	148,935 (87.6)	65,025 (91.1)	53,045 (89.5)	36,480 (90.5)	725,060 (86.2)	<0.001
EEG	46,830 (15.8)	31,965 (15.6)	21,150 (12.4)	6,375 (8.9)	6,215 (10.5)	3,850 (9.5)	116,385 (13.8)	

Abbreviations: IQR = interquartile range; NCHS = National Center for Health Statistics; NIS = National Inpatient Sample.
Full comorbidity data are available in eTable 1.

teaching hospitals (eTable 4C), patients from the most rural counties continued to be more likely to have a prolonged length of stay (OR 1.26 [95% CI 1.15–1.39], $p < 0.001$).

For nonroutine discharge (Table 3A), increasing rurality was associated with lower odds of nonroutine discharge (OR 0.98 [95% CI 0.97–0.99], p for trend <0.001). When analyzed categorically, patients from the most rural counties experienced 10% lower odds of nonroutine discharge compared with patients from the most urban counties (OR 0.90 [95% CI 0.85–0.96], $p = 0.001$). Subanalysis of patients presenting in status epilepticus (eTable 2C) did not reveal a significant trend (OR 0.98 [95% CI 0.97–1.00], $p = 0.110$). In the subanalysis of patients with private insurance (eTable 3D), the association between rurality and nonroutine discharge continued to be observed (OR 0.98 [95% CI

Table 2 Increasing Rurality Was Associated With Higher Odds of In-Hospital Mortality, Presenting in Status Epilepticus, and Prolonged Length of Stay in Nationwide Epilepsy Admissions in the United States

A: In-hospital mortality			B: Status epilepticus at presentation			C: Prolonged length of stay		
NCHS rurality level	OR (95% CI)	*p* Value	NCHS rurality level	OR (95% CI)	*p* Value	NCHS rurality level	OR (95% CI)	*p* Value
1 (least rural; reference)	1		1 (least rural; reference)	1		1 (least rural; reference)	1	
2	1.08 (0.95–1.24)	0.249	2	1.09 (1.05–1.14)	<0.001	2	1.05 (1.00–1.10)	0.037
3	1.27 (1.11–1.45)	<0.001	3	1.16 (1.11–1.21)	<0.001	3	1.04 (0.99–1.09)	0.137
4	1.43 (1.20–1.71)	<0.001	4	1.16 (1.10–1.22)	<0.001	4	1.09 (1.02–1.16)	0.011
5	2.22 (1.83–2.70)	<0.001	5	1.34 (1.26–1.43)	<0.001	5	1.35 (1.25–1.46)	<0.001
6 (most rural)	1.93 (1.56–2.39)	<0.001	6 (most rural)	1.32 (1.24–1.41)	<0.001	6 (most rural)	1.29 (1.19–1.41)	<0.001
Trend	1.16 (1.12–1.20)	<0.001	Trend	1.06 (1.05–1.07)	<0.001	Trend	N/A	N/A

Abbreviations: NCHS = National Center for Health Statistics; OR = odds ratio.
Logistic regression models of the effect of rurality on in-hospital mortality, presenting in status epilepticus, and prolonged length of stay in nationwide epilepsy admissions in the US cohort drawn from the National Inpatient Sample, years 2016–2021. The Box-Tidwell test for prolonged length of stay found evidence of significant nonlinearity: accordingly, a trend analysis is not reported. All models adjusted for demographics, comorbidities, and hospital characteristics (in Methods).

0.97–0.99], *p* for trend <0.001). In the subanalysis of patients admitted to urban teaching hospitals (eTable 4D), increasing rurality continued to be associated with lower odds of nonroutine discharge (OR 0.98 [95% CI 0.97–0.99], *p* for trend = 0.004).

For EEG, tests for trend were not performed because of evidence of nonlinearity. When analyzed categorically, patients from the most rural counties experienced 12% lower odds of receiving EEG compared with patients from the most urban counties (OR 0.88 [95% CI 0.77–1.00], $p = 0.047$). Subanalysis of patients presenting in status epilepticus (eTable 2D) revealed a similar association, with patients from the most rural counties experiencing 18% lower odds of receiving EEG compared with patients from the most urban counties (OR 0.82 [95% CI 0.68–0.99], $p = 0.040$). In the subanalysis of patients with private insurance (eTable 3E), patients from the most rural counties similarly had lower odds of receiving EEG (OR 0.88 [95% CI 0.77–1.00], $p = 0.047$). In the subanalysis of patients admitted to urban teaching hospitals (eTable 4E), patients from the most rural counties did not have lower odds of receiving EEG (OR 0.89 [95% CI 0.78–1.02], $p = 0.098$).

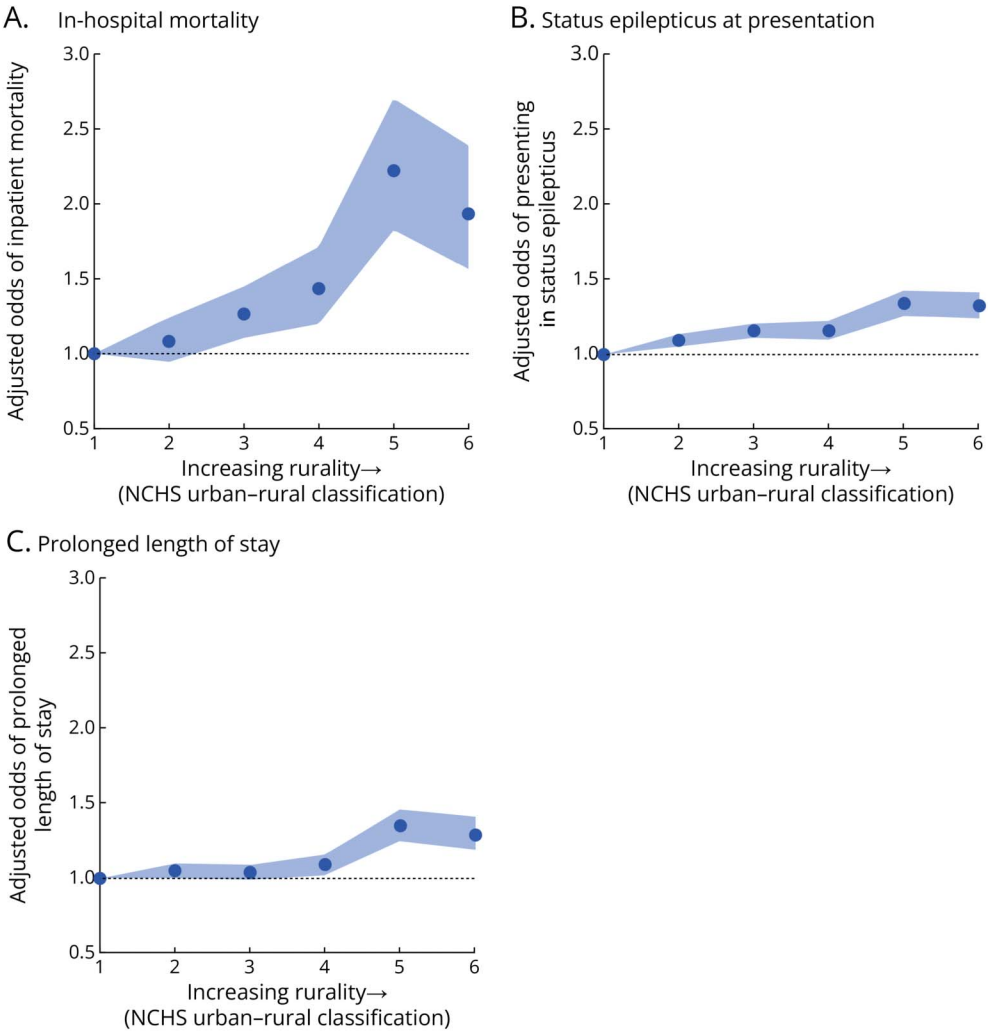
Discussion

In this study, we found that increasing rurality was independently associated with worse epilepsy outcomes, most notably with nearly double the odds of in-hospital mortality, compared with those from the most urban counties. Rurality was also linked to a higher likelihood of presenting in status epilepticus and a prolonged hospital stay. By contrast, rurality was associated with lower odds of nonroutine discharge and receipt of EEG. These associations remained when subanalyzing patients presenting in status epilepticus. Notably, the associations between mortality, presenting in status epilepticus, and prolonged length of stay were attenuated in patients with private insurance.

Several mechanisms may explain why rurality is associated with worse epilepsy outcomes. One key factor is limited seizure control. Because of their remote location, rural patients may have less frequent access to neurologists, leading to suboptimal medication management, and medication access itself is also more difficult, as many people with epilepsy are unable to drive and transportation barriers are frequently cited as a reason for poor medication adherence.[29,30] Accordingly, rural people with epilepsy may experience more severe baseline seizures and an increased risk of sudden unexpected death in epilepsy.[31] These challenges are further compounded by a scarcity of nearby hospitals, the concentration of comprehensive epilepsy centers in metropolitan regions,[7] and limited access to surgical procedures.[18]

Increasing rurality may also negatively affect acute seizure care. For status epilepticus, poor outcomes have previously been linked to delayed hospital arrival and limited access to EEG.[32-34] In our study, rurality was associated with reduced odds of receiving EEG, a gap that may contribute to diagnostic delays and increased risk of status epilepticus–related

Figure 2 Forest Plots of Epilepsy Outcomes by Rurality



Forest plots of adjusted ORs and 95% CIs of in-hospital mortality (A), presentation in status epilepticus (B), and prolonged length of stay (C) in nationwide epilepsy admissions in the United States, by patients' rurality. As rurality increased, adjusted odds of in-hospital mortality (OR 1.16 [95% CI 1.12–1.20], p for trend <0.001) and status epilepticus at presentation (OR 1.06 [95% CI 1.05–1.07], p for trend <0.001) increased. A trend test was not performed for length of stay because of evidence of significant nonlinearity. Relative to patients from the most urban counties, patients from the most rural counties had increased odds of in-hospital mortality (OR 1.93 [95% CI 1.56–2.39], $p < 0.001$), status epilepticus at presentation (OR 1.32 [95% CI 1.24–1.41], $p < 0.001$), and prolonged length of stay (OR 1.29 [95% CI 1.19–1.41], $p < 0.001$). All models were adjusted for age, race or ethnicity, primary expected payer, smoking status, Elixhauser comorbidities, hospital size (bed count), hospital teaching status, hospital control/ownership, census region of hospital, median household income quartile for patients' ZIP code, and rurality. NCHS = National Center for Health Statistics; OR = odds ratio.

Table 3 Logistic Regression Models of the Effect of Rurality on Nonroutine Discharge and Odds of Receiving EEG in Nationwide Epilepsy Admissions in the US Cohort Drawn From the National Inpatient Sample, Years 2016–2021

A: Nonroutine discharge			B: Odds of receiving EEG		
NCHS rurality level	**OR (95% CI)**	***p* Value**	**NCHS rurality level**	**OR (95% CI)**	***p* Value**
1 (least rural; reference)	1		1 (least rural; reference)	1	
2	0.96 (0.93–1.00)	0.028	2	0.98 (0.91–1.06)	0.691
3	0.97 (0.94–1.01)	0.112	3	0.80 (0.71–0.89)	<0.001
4	0.89 (0.85–0.94)	<0.001	4	0.69 (0.61–0.77)	<0.001
5	0.94 (0.89–0.99)	0.023	5	1.02 (0.90–1.14)	0.782
6 (most rural)	0.90 (0.85–0.96)	0.001	6 (most rural)	0.88 (0.77–1.00)	0.047
Trend	0.98 (0.97–0.99)	<0.001	Trend	N/A	N/A

Abbreviations: NCHS = National Center for Health Statistics; OR = odds ratio.
The Box-Tidwell test for receipt of EEG found evidence of significant nonlinearity: accordingly, a trend analysis is not reported. All models adjusted for demographics, comorbidities, and hospital characteristics (in Methods).

mortality. Previous work has also demonstrated that longer time to treatment is associated with prolonged status epilepticus.[35] Given that many patients with epilepsy do not receive prehospital treatment[36] and rural patients face longer transport times, strengthening emergency medical services to facilitate earlier seizure recognition and timely medication delivery may be important for improving epilepsy outcomes.

In the subanalysis of those patients with private insurance, the associations between rurality and in-hospital mortality, presenting in status epilepticus, and prolonged length of stay were no longer observed. Previous studies have shown that adults with active epilepsy are more likely to be insured under Medicaid and less likely to have private insurance.[37,38] In addition, the availability of epilepsy centers did not influence access to specialized care in those with private insurance,[39] and patients with private insurance are more likely to experience shorter wait times and to undergo epilepsy surgery.[40] Taken together, these findings suggest that private insurance may mitigate some of the structural barriers faced by rural patients, thereby attenuating the observed rural-urban disparities in epilepsy outcomes.

Increasing rurality was also associated with a prolonged length of stay. Rural patients may experience delayed access to care, extending hospitalization. These patients may also present later in the disease course (e.g., in status epilepticus or uncontrolled seizures), further prolonging their stay. Despite greater odds of prolonged length of stay, rural patients had lower odds of nonroutine discharge, which may reflect limited availability of postacute care facilities in rural areas,[41] resulting in more patients being discharged home rather than to rehabilitation or skilled nursing facilities. A higher proportion of rural patients being uninsured or underinsured may also underlie this association,[42] as these patients have less access to rehabilitation facilities.

Our findings of worse epilepsy outcomes with increasing rurality mirror those in a recent study, which found that EEG was less likely to be performed in rural hospitals among patients presenting in status epilepticus.[6] Notably, using hospital classification as a proxy for patient rurality may misclassify patients because many rural residents receive care in urban hospitals, as was observed in our cohort. While we observed that rural patients admitted to urban teaching hospitals were not more likely to have a nonroutine discharge or receive EEG than their most urban counterparts, we nevertheless found that they continued to exhibit increased odds of mortality, presenting in status epilepticus, and a prolonged length of stay: this suggests that the deleterious effects of rurality persist regardless of the hospital type patients are admitted to. A 2021 systematic review found only a small number of studies investigating rurality and epilepsy, with inconsistent reporting of outcomes and with overall mixed results.[43] Of the 3 studies exploring epilepsy outcomes in the United States, each was conducted at the state level and included varying definitions of rurality, limiting comparability.[44-46] Future studies should use standardized rurality measures to accurately quantify disparities in epilepsy care. Exploratory subanalyses examining epilepsy etiology suggested that rural-urban disparities in mortality were present among patients with poststroke epilepsy, but not among those with tumor-associated epilepsy. The absence of a similar association in tumor-associated epilepsy may reflect the generally poor prognosis associated with intracranial malignancies, potentially masking the effect of rurality on mortality. However, the NIS lacks detailed etiology data, which prevents definitive etiologic classification. These analyses are, therefore, exploratory and should be interpreted cautiously, particularly given the limited sample sizes within etiologic subgroups.

Broadly, our findings should be interpreted within the context of a nationwide increase in demand for neurologic care alongside a growing shortage of neurologists.[47] On average, 1 in 5 Medicare recipients must travel 50 or more miles to receive neurologic care,[48] a challenge exacerbated by the closure of 153 rural hospitals since 2010.[49] As a result, people with epilepsy residing in rural counties may be disproportionately affected by accessibility barriers. Ultimately, there is a critical need for targeted interventions to improve epilepsy outcomes in rural populations. To expand access, some providers have reported success using telehealth visits for epilepsy care,[50] which may improve seizure control and outcomes. Other important strategies include expanding rapid or conventional EEG availability in rural hospitals,[51] increasing epilepsy-specific training among providers,[52] and facilitating medication access through mail-order pharmacy services. Expanding access to comprehensive epilepsy centers[7] and epilepsy surgery[18] for rural populations may further improve outcomes. Future research should identify which rural subpopulations are at highest risk, examining factors such as insurance type and access to specialized epilepsy services.

Our study has several limitations. Inherent to any observational study design is the potential for latent confounding, and there were several factors we were unable to control for in our analyses. Notably, although we were able to adjust for presence of status epilepticus, we were unable to adjust for other seizure severity measures such as seizure frequency, subtype, and duration. In addition, we could not account for emergency medical services availability, travel time/time to presentation, and geographic distance to hospitals and epilepsy centers.[48] Future studies should incorporate more precise severity and accessibility measures. Second, the NIS only includes patients admitted to hospitals in the United States, limiting generalizability to other populations and countries with different health care systems. We also note that, owing to the structure of the NIS's sex and race/ethnicity variables, values are provided by hospitals and, therefore, exact reporting practices may vary; in addition, race/ethnicity data in the NIS are collapsed into 1 variable, limiting the ability to disambiguate racial/ethnic differences in this study. Notably, our

cohort (2016–2021) largely predates the widespread expansion of telehealth services after the coronavirus disease 2019 pandemic: it may be that the adoption of telehealth for epilepsy care can help mitigate some of the observed rural-urban disparities by addressing transportation barriers and the shortage of local epileptologists.[53,54] Third, our analysis was limited to hospitalizations, preventing assessment of longitudinal outcomes such as sudden unexpected death in epilepsy, status epilepticus prevalence, or rehospitalization rates. It is also possible that a subset of rural patients may be entirely unable to access inpatient care—for example, because of socioeconomic barriers or inadequate transportation—representing a particularly vulnerable population that our study cannot capture. Consequently, the absence of outpatient outcome data may lead to an underestimation of the true magnitude of rural-urban disparities in epilepsy. Finally, because the NIS does not support patient-level linkage, it is possible that patients may contribute multiple hospitalizations, such as in the case of a rural-to-urban transfer. Nevertheless, regarding our primary outcome of in-hospital mortality, such double counting would likely result in an underestimate of rural-urban mortality differences because transferred patients have necessarily survived their initial hospitalization. Moreover, our findings were broadly unchanged in subanalyses restricted to admissions to urban teaching hospitals, suggesting that rural-to-urban transfers do not meaningfully drive the observed rural-urban disparities.

Among patients with epilepsy, rural residence was independently associated with higher in-hospital mortality, greater likelihood of status epilepticus at presentation, and higher odds of prolonged length of stay. Reduced access to EEG may also contribute to poor outcomes. These findings highlight an important health care disparity, with significant public health implications. Strengthening rural health infrastructure for people with epilepsy is required, including expanding telehealth services, improving EEG availability, increasing access to comprehensive epilepsy centers and epilepsy surgery, and enhancing epilepsy training among health care providers and emergency medical services.

Author Contributions

E.R. Bader: drafting/revision of the manuscript for content, including medical writing for content; major role in the acquisition of data; study concept or design; statistical analyses; analysis or interpretation of data. W.S. Kemball-Cook: drafting/revision of the manuscript for content, including medical writing for content; analysis or interpretation of data. J. Benton: drafting/revision of the manuscript for content, including medical writing for content; analysis or interpretation of data. N.J. Killian: analysis or interpretation of data. A. Boro: drafting/revision of the manuscript for content, including medical writing for content; analysis or interpretation of data. E.N. Eskandar: drafting/revision of the manuscript for content, including medical writing for content; analysis or interpretation of data.

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Disclosure

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