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Title. Geographical Variation in TBI Mortality by Proximity to the Nearest Neurosurgeon
Short Title. TBI Mortality & Neurosurgeon Proximity

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HR collected the data, performed the statistical analysis, and drafted the manuscript/figures. GK and JM conceived of the presented idea and drafted the manuscript. DJ served as the principal investigator for this research and assisted with conceptualization of the idea, the statistical analysis, and editing. All authors discussed the results and contributed to the final manuscript.

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Abstract

Background: Trauma mortality disproportionately affects populations farther from potentially lifesaving trauma care, and traumatic brain injury (TBI) is no exception. Previous examinations have examined proximity to trauma centers as an explanation for trauma mortality, but little is known about the relationship between proximity to neurosurgeons specifically in TBI mortality.

Materials & Methods: In this cross-sectional study, county level TBI mortality rates from 2008 to 2014 were examined in relation to the distance to the nearest neurosurgeon and trauma facility. The locations of practicing neurosurgeons and trauma facilities in the United States were determined by geocoding data from the 2017 Medicare Physician and Other Supplier and Provider of Services files (respectively). The association between TBI mortality and the distance from the population-weighted centroid of the county to closest neurosurgeon and trauma facility was examined using multivariate negative binomial regression.

Results: 761 of the 3108 counties (24.5%) in the continental US were excluded from the analysis because they had 20 or fewer TBI deaths during this time, producing unstable estimates. Excluded counties accounted for 1.67% of the US population. Multivariate analysis revealed a county's mortality increased 10% for every 25-miles from the nearest neurosurgeon (adjusted incident rate ratio [aIRR]: 1.10 [95% CI: 1.08 – 1.12]; p<0.001). The distance to the nearest trauma facility was not found to be significantly associated with mortality (aIRR: 1.01 [95% CI: 0.99 – 1.03]; p=0.36).

Conclusions: These findings suggest that proximity to neurosurgeons may influence county-level TBI mortality. Further research into this topic with more granular data may help to allocate scarce public health resources.

Keywords: Traumatic Brain Injury; Health Services Accessibility; Rural health services; Resource utilization; Neurosurgery; Trauma systems improvement

Introduction

Traumatic Brain Injuries (TBI) led to 2.8 million emergency department visits, hospitalizations, or deaths in the United States in 2013[1]. With so many cases, TBIs are a major burden for the health care system. However, this burden is not shared equally across geographical areas, with rural areas facing worse TBI outcomes than urban areas[2]. There are well established disparities in trauma care for rural populations that have been demonstrated in trauma patients generally[3–5], and in neurosurgical patients specifically[2,6].

Various authors have explored the idea that proximity to level I and II trauma care facilities is a potential explanation for these disparities[3–5,7,8]. However, this proximity may not adequately describe access to care in rural areas. Specifically, there tend to be fewer level I and II trauma centers in rural than in urban areas, while at the same time there may still be practicing neurosurgeons in these rural areas. Conversely, some counties might have access to trauma facilities that do not staff any neurosurgeons (e.g. many level III or IV trauma centers[9]) that still could provide lifesaving care to TBI patients in the absence of an available neurosurgeon. Thus, proximity to neurosurgeons and proximity to trauma facilities (of any level) may be more appropriate metrics than distance to level I or II trauma facilities alone[9].

Given this, and the fact that the management of TBIs often requires neurosurgical evaluation or intervention, the geographical distribution of neurosurgeons across the United States is of interest. To the best of our knowledge, no study has examined the national geographic distribution of practicing neurosurgeons, and its relation to TBI outcomes. Our primary objective was to assess the relationship between the geographic distribution of neurosurgeons and TBI mortality.

Methods

Study Design

In this cross-sectional study, TBI mortality rates and distance to the nearest neurosurgeon were analyzed at a county level. Because this was an analysis of publicly available, de-identified data it was determined not to be human subjects research and does not require IRB approval. All data were collected and analyzed between January and March 2020. This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline.

Primary outcome

We determined the TBI-specific mortality rate for each US county using the Centers for Disease Control and Prevention's Web-based Injury Statistics Query and Reporting System (WISQARS) database for fatal injuries. WISQARS defines TBI deaths using the *International Classification of Diseases, 10th Revision codes* S01.0–S01.9, S02.0, S02.1, S02.3, S02.7–S02.9, S04.0, S06.0–S06.9, S07.0, S07.1, S07.8, S07.9, S09.7–S09.9, T90.1, T90.2, T90.4, T90.5, T90.8, or T90.9. We collected both age-adjusted and crude mortality rates from 2008 to 2014, for each county. The rates for counties with 20 or fewer deaths during this period are not reported in WISQARS as their estimation is unstable, and thus these counties are excluded from our analysis.

Identifying locations of neurosurgeons and trauma facilities

To identify the distribution of practicing neurosurgeons in the United States, we used the 2017 Medicare Provider Utilization and Payment Data: Physician and Other Supplier public use file (PUF). The provider PUF contains summaries of 100% of fee-for-service claims, aggregated for each physician who billed Medicare during 2017. In addition to each physician's National Provider Identifier (NPI) number, the provider PUF also contains the physician's full name, specialty, and address. We determined the location of each neurosurgeon by geocoding their location based on (1) the full address provided in the provider PUF and (2) using the search query "[physician's full name] neurosurgeon in [state]" for each physician, using the Google Maps geocoding API. We limited our analysis to physicians with a reported specialty of "neurosurgeon" who were practicing in the continental United States (4,425 neurosurgeons).

Facilities providing trauma services were identified using the 2017 Medicare Provider of Services file, which contains data on all individual healthcare facilities participating in Medicare, including their address, facility type, and services provided at the facility. Trauma facilities were defined as hospitals (either short term hospitals or critical access hospitals) located in the continental United States who reported that they offered designated trauma center services during 2017 (1,718 trauma facilities).

County level covariates

Counties were categorized by level of urbanization based on their 2013 Rural-Urban Continuum Codes. Rural-Urban Continuum Codes range from 1 (most urban) to 9 (most rural) and were developed by the US Department of Agriculture to classify counties by population, degree of urbanization, and proximity to nearby metropolitan areas[10]. We considered codes 1 to 3 to be metropolitan, codes 4 to 7 to be non-metropolitan, and codes 8 and 9 to be rural. For each county we additionally collected demographic estimates (percentage male, percentage aged 65 or older) using the American Community Survey, as these factors are well established determinants of TBI mortality[11,12].

For each county, the distances to the closest neurosurgeon and trauma facility were identified by computing the distance from the county's population-weighted centroid to the nearest neurosurgeon or trauma facility (respectively). Distances were calculated in miles using the *sf* package in R, which computes the distance between two points as the great circle distance in miles[13].

Statistical Analysis

Bivariate analysis consisted of t-tests, chi-squared tests, or simple linear regression as appropriate. If assumptions of normality were not met based on visual inspection of QQ plots, non-parametric alternatives (Mann-Whitney U test for bivariate analysis of continuous variables) were used. Because the data was too dispersed for Poisson regression, negative binomial regressions were used to estimate the association of county-level TBI mortality with the exposure variables. Models were derived using distance to neurosurgeon in miles (primary exposure variable), distance to nearest trauma facility in miles, proportion of the county that was male, proportion of the county aged 65 years or older, and level of urbanization. To assess potential confounding by the underlying age structure of the counties populations, we also conducted a sensitivity analysis using projected death counts based on the age-adjusted mortality rates. All hypothesis testing was two-sided with a $p < 0.05$ threshold for statistical significance. Analysis was conducted in R (version 3.6.3).

Results

Univariate descriptive statistics for each variable can be found in **Table 1**. The mean (95% CI) mortality rate among included counties was 23.60 (23.26 - 23.94) per 100,000 population (**Figure 1**). The mean (95% CI) distance to the nearest neurosurgeon was 27.52 (26.54 - 28.50) miles (**Figure 2**). **Figure 3** illustrates that neurosurgeons were most heavily concentrated in metropolitan counties (n=4283, 97.1%), with few located in non-metropolitan (n=126, 2.9%) or rural counties (n=2, 0.05%).

Missing TBI Rates

Among the 3,108 counties in the continental US, 761 did not have TBI mortality rates reported because they had 20 or fewer TBI deaths. When compared with counties included in our analysis, the counties with missing TBI mortality rates tended to have a greater proportion of their population who were male (50.8% vs 49.7%; $p < 0.001$), or 65 years or older (18.8% vs 15.2%; $p < 0.001$), tended to be farther from the nearest neurosurgeon (60.1 vs 27.5 miles; $p < 0.001$) and trauma facility (26.8 vs 20.5 miles; $p < 0.001$), and to be less urban (**Appendix Table 1**). Counties with missing rates also tended to have smaller populations (mean ± SD: 47,063 ± 28,671) than counties without missing data (907,679 ± 2,526,655; $p<0.001$), and all together counties with missing rates only accounted for 1.67% of the US population.

Mortality rates

The unadjusted column of **Table 2** presents the bivariate analysis, expressed as incident (mortality) rate ratios (IRRs). The mortality rate increased by 19% per 25-mile increase in distance to the nearest neurosurgeon (incident risk ratio [IRR]: 1.19 [95% CI: 1.17 – 1.20]) and 12% per 25-mile increase in distance to the nearest trauma facility (IRR: 1.12 [95% CI: 1.10 – 1.15]). Compared to metropolitan counties, rural counties had a 75% higher mortality rate (IRR: 1.75 [95% CI: 1.66 – 1.84]), followed by non-metropolitan counties (IRR: 1.33 [95% CI: 1.29 – 1.36]). Mortality rate was also significantly associated with the proportions of the county that was male, and the percent ≥65 years old on bivariate analysis ($p<0.001$ for both, **Table 2**).

Multivariate analysis

On multivariate analysis, mortality rate was significantly associated with distance to neurosurgeon, as revealed by the adjusted column of **Table 2**. After adjusting for other covariates, each 25-mile increase in distance to the nearest neurosurgeon was associated with a 10% relative increase in the mortality rate (adjusted incident risk ratio [aIRR]: 1.10 [95% CI: 1.08 – 1.12]). However, distance to trauma facility was not significantly associated with mortality on multivariate analysis (aIRR: 1.01 [95% CI: 0.99 – 1.03]; p=0.36). Compared to metropolitan counties, rural counties had a 35% higher mortality rate (aIRR: 1.35 [95% CI: 1.28 – 1.43]), while non-metropolitan counties had an 11% relative increase in mortality rate (aIRR: 1.11 [95% CI: 1.08 – 1.14]). A county's age was also associated with higher mortality, with a 3% relative increase in mortality rate for each percent of the county's populated aged 65 years or older (aIRR: 1.03 [95% CI 1.026 – 1.033]). However, the proportion of the county that was male was not significantly associated with mortality (aIRR: 1.01 [95% CI: 0.99 – 1.01]; p=0.09). Results of the multivariate regression using age-adjusted mortality were similar to those presented above (**Table 3**, Model B), with similar coefficients for distance to neurosurgeon (aIRR: 1.11 [95% CI: 1.09 – 1.13]; p < 0.001) and trauma facility (aIRR: 1.01 [95% CI: 0.994 – 1.03]; p = 0.17).

Discussion

Our investigation demonstrates evidence that distance from the nearest neurosurgeon is associated with county level TBI mortality, even after controlling for distance to trauma facilities, degree of urbanization, and other covariates. To our knowledge, this is the first investigation to examine TBI mortality as it relates to both distance to neurosurgical care and distance to trauma facilities, on a national scale.

The results of the present analysis demonstrate that neurosurgeons are most heavily concentrated in more urban areas, with few neurosurgeons practicing in rural or non-metropolitan areas (Figure 3). These findings align with previous studies which found that higher level trauma centers (level 1 or 2 trauma centers) staff more neurosurgeons than lower level trauma centers, and that over half of America's rural population lives over 60 minutes away from a level 1 or 2 trauma center[4,9]. Together these findings suggest that rural areas are covered largely by lower level trauma facilities, most of which lack dedicated neurosurgical coverage. It should be noted, however, that over 90% of practicing neurosurgeons cover emergency call at multiple hospitals, so it is possible that some neurosurgeons who are primarily located in more urban counties do provide emergency coverage in nearby less urban counties[14].

The findings that the distance to neurosurgeon, but not trauma facility, was associated with county level mortality raises interesting questions. Management of complex trauma patients requires expertise, and prior studies have demonstrated improved outcomes at higher level trauma centers, for patients with severe injuries[8,15,16]. It is likely that many of these rural trauma facilities see lower volumes of TBI patients, which has previously been established as a risk factor for poor outcomes[17]. Additionally, depending on patient severity and local emergency medical services (EMS) protocols, some patients transported by air EMS may be transported directly to a higher level trauma facility (bypassing the nearest trauma center).

These results do not imply that access to neurosurgical coverage is the sole determinant of county level TBI mortality, as numerous other factors likely also play a role. For example, an analysis of access to neurocritical care units revealed large geographic disparities in access across the United States, and found that only one third of Americans lived within 90 minutes of a neurocritical care unit[18]. It is also likely that social determinants of health contribute to county level mortality, such as insurance status, poverty, and occupation[12,19].

Strengths & Limitations

Our study identified all practicing neurosurgeons and trauma facilities in the United States (who billed Medicare) and identified their locations with a high level of precision, providing us with a complete picture of the geographic distribution of neurosurgeons and trauma facilities. Unlike studies that use distance to the nearest level 1 or 2 trauma center alone, we included proximity to a neurosurgeon specifically to account for neurosurgeons in more rural areas that may not be practicing at a level 1 or 2 trauma center.

This present study has several limitations. First, the unit of analysis in this study is county level TBI mortality, and therefore these population inferences cannot be extrapolated to the level of individuals. Because of this important limitation, additional factors that operate at the individual level such as baseline health status or the nature of the injury may also be influencing the patterns of TBI mortality at the county level. Ideally, this association could be examined with individual level data, but this is practically impossible to accomplish at a national level in the United States. Second, counties with fewer than 20 TBI related deaths were excluded from our analysis. Although these excluded counties only contained a small fraction of the US population (1.67%), they account for nearly a quarter of US counties. Likely these counties had fewer than 20 deaths due to their smaller populations (thus needing higher per capita mortality rates in order to achieve the same number of deaths as larger counties).

Additionally, this study uses TBI mortality aggregated across multiple years (from 2008 to 2014). While this is necessary in order to capture TBI deaths in counties with relatively low populations, it also introduces potential limitations, because the geographic distribution of neurosurgeons and trauma facilities during 2008 is likely not the same as in 2014. Therefore, it is possible that the geographic distribution of trauma/neurosurgical services during the early years of this time period may not be reflective of the distributions used in this study. Finally, because the data source used for TBI mortality in this study (WISQARS) is based on national vital statistics, we are unable to ascertain details on the time from injury to death. This could also allow for the distribution of services to change during the time from injury to death.

Conclusions & Implications

Further research with individual level data is needed to help better serve these communities and to better understand this relationship at an individual level. Furthermore, in addition to the distance to trauma centers and rurality, policymakers should consider proximity to neurosurgeons when considering how to allocate scarce public health resources.

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Table 1: Descriptive statistics

	All counties (N = 3,108)
Distance to nearest neurosurgeon (miles)	
Mean (95% CI)	35.68 (34.57 – 36.80)
Median (IQR)	28.57 (14.69 – 47.62)
Distance to nearest trauma facility (miles)	
Mean (95% CI)	22.05 (21.40 – 22.70)
Median (IQR)	19.99 (5.67 – 32.24)
% of county that is male	
Mean (95% CI)	49.96 (49.88 – 50.04)
Median (IQR)	49.53 (48.83 – 50.43)
% county that is 65 or older	
Mean (95% CI)	16.10 (15.95 – 16.25)
Median (IQR)	15.71 (13.28 – 18.37)
Urbanization	
Metro	1,160 (37%)
Nonmetro	1,321 (43%)
Rural	627 (20%)
Population	
Mean (95% CI)	696,955 (618,677 – 775,233)
Median (IQR)	181,625 (78,793 – 469,778)

Univariate descriptive statistics of counties in the continental United States

CI = confidence interval; IQR = interquartile

Table 2: Unadjusted and adjusted mortality rates

	Unadjusted		Adjusted	
	IRR (95% CI)	**p value**	**aIRR (95% CI)**	**p value**
Distance to neurosurgeon†	1.19 (1.17 - 1.2)	**<0.001**	1.10 (1.08 - 1.12)	**<0.001**
Distance to trauma facility†	1.12 (1.1 - 1.15)	**<0.001**	1.01 (0.99 - 1.03)	0.363
Urbanization (reference: Metro)				
Non-Metro counties	1.33 (1.29 - 1.36)	**<0.001**	1.11 (1.08 - 1.14)	**<0.001**
Rural counties	1.75 (1.66 - 1.84)	**<0.001**	1.35 (1.28 - 1.43)	**<0.001**
Male (%)	1.02 (1.01 - 1.03)	**<0.001**	1.01 (0.999 - 1.01)	0.086
65 years or older (%)	1.04 (1.04 - 1.05)	**<0.001**	1.03 (1.03 - 1.03)	**<0.001**

Combined bivariate (unadjusted column) and multivariate (adjusted column) negative binomial regressions for county level mortality. Results are shown as incident (mortality) rate ratios.

† Incident rate ratios shown are per 25 miles of distance

Abbreviations: IRR = *Incident rate ratio*; aIRR = *Adjusted incident rate ratio*; 95% CI = *95% confidence interval*

Table 3: Sensitivity Analysis

	Crude Rate (A)	**Age Adjusted** (B)
Distance to neurosurgeon†	1.1 (1.08 - 1.12) ***	1.11 (1.09 - 1.13) ***
Distance to trauma facility†	1.01 (0.99 - 1.03)	1.01 (0.994 - 1.03)
Urbanization (reference: Metro)		
Non-Metro counties	1.11 (1.08 - 1.14) ***	1.11 (1.08 - 1.15) ***
Rural counties	1.35 (1.28 - 1.43) ***	1.42 (1.35 - 1.51) ***
Male (%)	1.01 (0.999 - 1.01)	1.00 (0.997 - 1.01)
65 years or older (%)	1.03 (1.03 - 1.03) ***	1.01 (1.01 - 1.02) ***

Results of sensitivity analysis presented as adjusted incident (mortality) rate ratios with 95% confidence intervals in parenthesis. **Model A** represents the multivariate regression from the main analysis (identical to "adjusted" column in Table 2). **Model B** uses age adjusted TBI mortality (versus crude mortality used in model A). Stars represent significance levels, with three stars (***) indicating p < 0.001

† Incident rate ratios shown are per 25 miles of distance

Appendix Table 1: Excluded counties

	Total (N = 3,108)	**Included** (N = 2,342)	**Excluded** (N = 766)	**p-value**
Distance to nearest neurosurgeon (miles)				p < 0.001 †
Mean (95% CI)	35.68 (34.57 – 36.80)	27.52 (26.54 – 28.50)	60.84 (58.12 – 63.57)	
Median (IQR)	28.57 (14.69 – 47.62)	23.64 (8.04 – 38.79)	50.71 (34.16 – 77.44)	
Distance to nearest trauma facility (miles)				p < 0.001 †
Mean (95% CI)	22.05 (21.40 – 22.70)	20.50 (19.79 – 21.21)	26.82 (25.39 – 28.26)	
Median (IQR)	19.99 (5.67 – 32.24)	18.08 (4.98 – 30.11)	24.67 (10.54 – 37.82)	
% Male				
Mean (95% CI)	49.96 (49.88 – 50.04)	49.69 (49.62 – 49.77)	50.78 (50.54 – 51.02)	
Median (IQR)	49.53 (48.83 – 50.43)	49.40 (48.77 – 50.14)	50.06 (49.17 – 51.24)	
% 65 or older				p < 0.001 †
Mean (95% CI)	16.10 (15.95 – 16.25)	15.22 (15.08 – 15.37)	18.77 (18.44 – 19.10)	
Median (IQR)	15.71 (13.28 – 18.37)	15.07 (12.88 – 17.13)	18.56 (15.77 – 21.66)	
Urbanization				p < 0.001 ‡
Metro (%)	1,160 (37%)	1,068 (46%)	92 (12%)	
Nonmetro (%)	1,321 (43%)	1,109 (47%)	212 (28%)	
Rural (%)	627 (20%)	165 (7%)	462 (60%)	
Population				p < 0.001 §
Mean (95% CI)	696,955 (618,677 – 775,233)	909,128 (806,698 – 1,011,557)	48,249 (45,578 – 50,921)	
Median (IQR)	181,625 (78,793 – 469,778)	276,864 (149,319 – 689,892)	44,017 (24,531 – 64,188)	

† Unpaired t-test
‡ Chi-squared
§ Mann-Whitney

Comparison of the counites excluded in the analysis to counties included. P-values are given for bivariate tests comparing the two groups. The Mann-Whitney U test was used to compare populations because a small number of counties had very large populations, violating the assumption of normality

Figures

Figure 1

Estimates of the crude TBI mortality rate (per 100,000) for each county. Rates from counties with 20 or fewer deaths reported from 2008 to 2014 are suppressed and are shaded grey (in the color version of this figure, available online) and white in the print version.

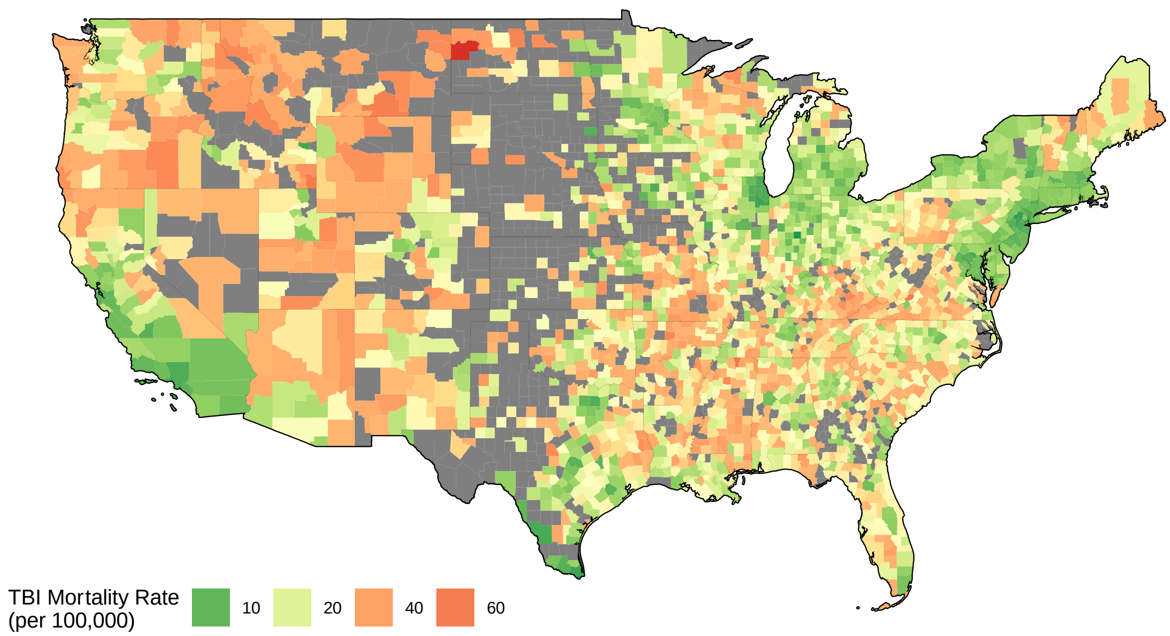


Figure 2

Distance to the nearest neurosurgeon (in miles) for each county. Counties that are shaded darker indicate an increased distance to the nearest neurosurgeon.

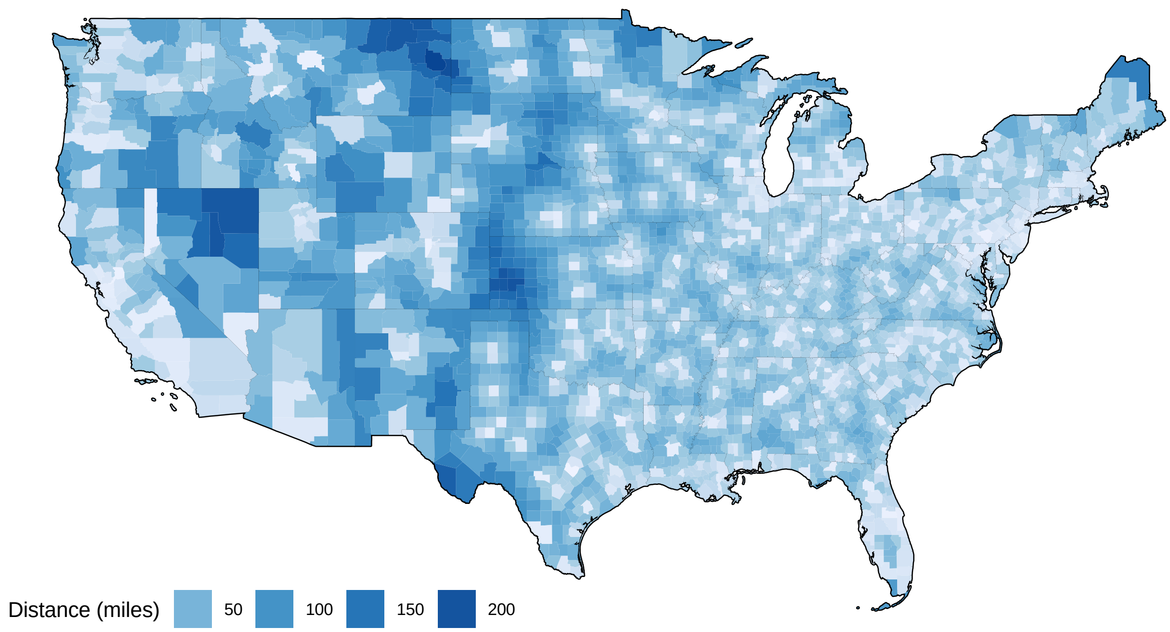
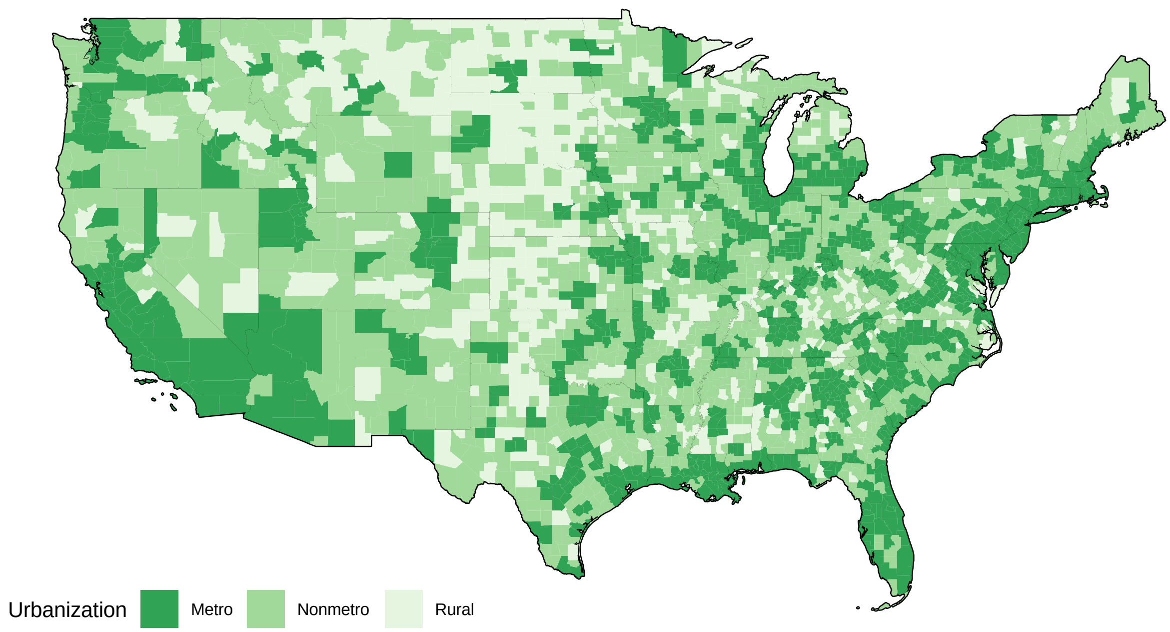


Figure 3

Counties by level of urbanization, where darker shades indicate a higher degree of urbanization. Each dot on the map indicates the location of each neurosurgeon.



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