Stroke

ORIGINAL CONTRIBUTION

Demographic Disparities in Proximity to Certified Stroke Care in the United States

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BACKGROUND AND PURPOSE: Demographic disparities in proximity to stroke care influence time to treatment and clinical outcome but remain understudied at the national level. This study quantifies the relationship between distance to the nearest certified stroke hospital and census-derived demographics.

METHODS: This cross-sectional study included population data by census tract from the United States Census Bureau's 2014–2018 American Community Survey, stroke hospitals certified by a state or national body and providing intravenous thrombolysis, and geographic data from a public mapping service. Data were retrieved from March to November 2020. Quantile regression analysis was used to compare relationships between road distance to the nearest stroke center for each census tract and tract-level demographics of age, race, ethnicity, medical insurance status, median annual income, and population density.

RESULTS: Two thousand three hundred eighty-eight stroke centers and 71 929 census tracts including 316 995 649 individuals were included. Forty-nine thousand nine hundred eighteen (69%) tracts were urban. Demographic disparities in proximity to certified stroke care were greater in nonurban areas than urban areas. Higher representation of individuals with age ≥65 years was associated with increased median distance to a certified stroke center in nonurban areas (0.51 km per 1% increase [99.9% CI, 0.42–0.59]) but not in urban areas (0.00 km [−0.01 to 0.01]). In urban and nonurban tracts, median distance was greater with higher representation of American Indian (urban: 0.10 km per 1% increase [0.06–0.14]; nonurban: 1.06 km [0.98–1.13]) or uninsured populations (0.02 km [0.00–0.03]; 0.27 km [0.15–0.38]). Each $10 000 increase in median income was associated with a decrease in median distance of 5.04 km [4.31–5.78] in nonurban tracts, and an increase of 0.17 km [0.10–0.23] in urban tracts.

CONCLUSIONS: Disparities were greater in nonurban areas than in urban areas. Nonurban census tracts with greater representation of elderly, American Indian, or uninsured people, or low median income were substantially more distant from certified stroke care.

GRAPHIC ABSTRACT: An online graphic abstract is available for this article.

Key Words: hospital ■ income ■ insurance ■ stroke ■ United States

The organization of acute stroke care in the United States establishes infrastructure and protocols to guide certified hospitals towards a standardized level of stroke care. However, the geographic distribution of certified stroke centers is variable, creating potential disparities between demographic groups that are also geographically clustered.[1–6] Given the impact of time to treatment on clinical outcomes in patients with acute ischemic stroke,[7–9] rigorously quantifying disparities between key demographic groups in access to timely care is essential to addressing potential gaps within the evolving stroke system of care. Identifying these disparities can help to direct ongoing efforts to reduce inequalities in access to life-saving stroke care.

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Prior studies have attempted to characterize access to stroke care in the United States. However, previous approaches have generally focused on small geographic regions or only partially represent the complex network of stroke hospitals that are certified by several different organizations.[10–13] For example, studies that account only for hospitals with national stroke center certifications may miss qualified centers with only state-level certification.[1,14–16]

In this work, we utilize population data from the United States Census Bureau, stroke center data from state and national certifying organizations, and geographic data from a public mapping service to rigorously quantify the relationship between key demographic characteristics of each census tract and distance to the nearest stroke hospital.

METHODS

Data Sources

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Population data were obtained at the census tract level to maximize spatial resolution. Census tracts are defined geographic subdivisions of counties and typically contain 1200 to 8000 people each, although the population may be outside this range. Demographic data for each census tract within the contiguous United States were obtained from the 2014–2018 American Community Survey 5-Year Estimates, which uses longitudinal data to provide statistically reliable characterization of even sparsely populated tracts.[17,18] The location of each census tract—defined as the geographic coordinates of the population-weighted centroid—and total land area were recorded from the United States Census Bureau.

Stroke hospital data were curated from national- and state-level databases of stroke certification.[2,4,16] National data were obtained from the Joint Commission, Healthcare Facilities Accreditation Program, or Det Norske Veritas Healthcare, all 3 of which are recognized by the American Stroke Association.[19–21] From the public websites of these organizations, we accessed the list of stroke hospitals certified by each. These national data were supplemented with state-level data obtained from websites of individual state governments, health departments, and emergency medical services which often maintain their own list of designated stroke hospitals. Hospitals were classified as certified stroke centers for this study if they were identified within at least one of these databases as a certified stroke center offering intravenous thrombolysis as of August 2020. Hospital locations, expressed as geographic coordinates, were identified by searching for addresses listed on hospital websites using online mapping services, OpenStreetMap (www.openstreetmap.org), and Google Maps (www.google.com/maps).

Road networks were obtained for each of the 48 contiguous states and the District of Columbia with open-source tools. A series of XML graphs were first downloaded from OpenStreetMap using OSMnx, a Python package to retrieve, model, and analyze real-world, drivable street networks.[22] This was accomplished by identifying a bounding box for each state using United States Census boundary data, then adding a buffer of one radian to account for cases in which the closest stroke center is located in an adjacent state. Then, coordinates for the resulting shape were used to query the OpenStreetMap API, which returned a road network for that state and its immediate surroundings. This network provided the basis for estimating road distances between census tracts and stroke centers in the corresponding state.

These data sources were public and not individually identifiable, and thus this study was classified as nonhuman subjects research exempt from review by our Institutional Review Board.

Distance Estimation

Distances from each census tract to the nearest stroke center were found using a 5-step process. First, 2 separate lists were generated: one containing the coordinates of the population-weighted centroid of each census tract in the contiguous United States and the other containing the coordinates of each hospital in the contiguous United States. Second, linear distance between each census tract and each hospital was estimated using a spherical geodesic length. Third, we identified the 3 stroke hospitals with shortest linear distance to each census tract without regard for state boundaries and classified these as candidates for nearest stroke hospital. Fourth, we calculated the shortest road distance from each census tract to each of its 3 candidate hospitals. Fifth, we identified the smallest of these 3 road distances for each census tract and classified the corresponding hospital as the nearest stroke center.

Shortest road distance between a census tract and a hospital was measured using NetworkX, a Python library used to study the structure of graphs and networks (www.networkx.org).[23] Using the graphs extracted from OpenStreetMap, routes were estimated by assigning nodes closest to each coordinate pair, then finding the minimum edge distance between those nodes (Figure 1). Because this method of computing road distance is time-consuming, limiting this computation to three candidate hospitals chosen for each census tract using a simpler distance metric achieves a reasonable balance between computational difficulty and search accuracy. Of note, this analysis considers only routes traversable by car because the graphs represent road networks.

Census Tract Classification

Each census tract was characterized by the composition by age, race, ethnicity, and insurance status, median annual income, and population density. Age was dichotomized around a threshold of 65 years, and age composition was defined as the proportion of the census tract population at least 65 years of age. Adopting the classifications used in the 2010 United States Census, race composition of each census tract was defined as the population proportions that were White, Black, Asian, Pacific Islander, American Indian, and Other, whereas ethnicity composition was defined as the population proportions that were Hispanic regardless of race. In this classification, Black includes African American, American Indian includes Alaska Native, Pacific Islander includes Native Hawaiian, Other includes other single races or >1 race, and Hispanic includes Latino. Insurance status composition of each census tract was defined as the percentage of the population without medical insurance. Population density was calculated as the ratio of the total population and total land area in each tract.

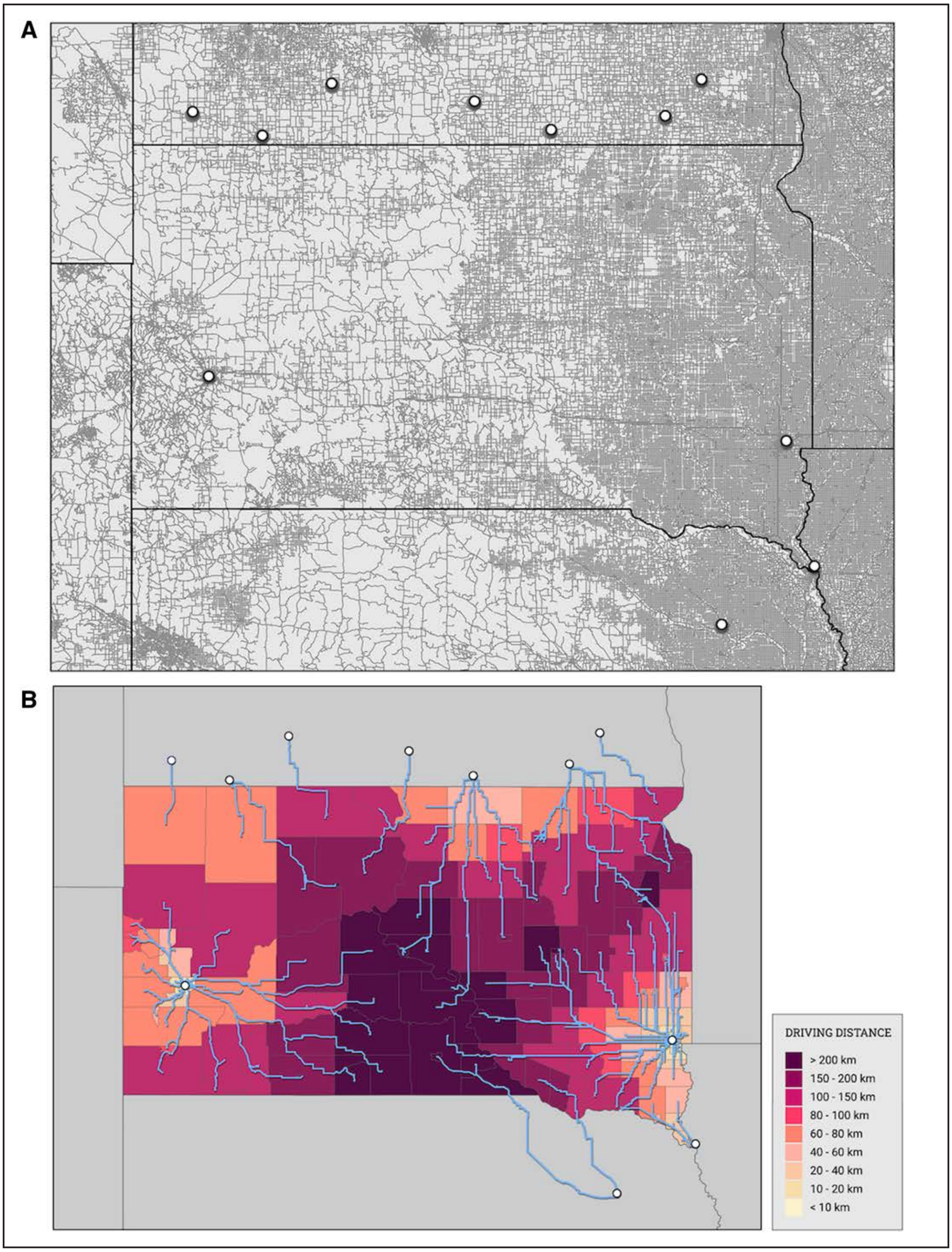

Figure 1. Method of distance estimation in South Dakota as a representative region.
A, Road network and locations of certified stroke hospitals (circles). **B**, Distance map showing shortest road route (blue lines) from each census tract to its nearest certified stroke hospital (circles). Driving distance for each census tract is determined by the total length of its shortest route. Routes are allowed to cross interstate boundaries.

Each census tract was further classified as urban or nonurban based on the location of the tract relative to the boundaries of urban areas defined in the 2010 Census.[18] This census defined each urban area around a core of census tracts with a minimum population density of 1000 people per square mile and extended to encompass geographically adjacent areas with a minimum population density of 500 people per square mile. The minimum requirement for total population of an urban area is 2500 people.[24] For our study, tracts with population-weighted centroids located within these Census-defined boundaries were classified as urban, and all others were classified as nonurban.

Data Analysis

Census tracts outside the contiguous United States or with a population of zero were excluded from analysis. Urban tracts and nonurban tracts were analyzed as separate subgroups.

We performed quantile regression analyses for urban and nonurban tracts to relate proximity to certified stroke care to the demographic composition of each census tract.[25] Distances were calculated for hypothetical urban and nonurban reference tracts with typical compositions. The urban reference tract was defined by the ratios of the total urban subpopulation of each demographic group to the total urban population, the population-weighted medians of median annual income, and population density. The nonurban reference tract was defined similarly. For each quantile regression analysis, proximity to a certified stroke center was analyzed for associations with underlying tract characteristics of age, race, ethnicity, medical insurance, income, and population density relative to the reference tract. This methodology naturally controls for confounding between tract characteristics and encodes sensitivity in regression estimates.

Analyses were conducted using IBM SPSS Statistics, Version 27.0 (IBM Corp; Armonk, NY). A conservative significance threshold of $\alpha=0.001$ was used to account for multiple comparisons. Regression outputs are reported as point estimates with 99.9% CIs.

RESULTS

Overview

Of the 72 539 census tracts in the contiguous United States, 71 929 tracts (99%) containing 316 995 649 people and 2388 stroke hospitals were included in this study. The 610 tracts (1%) that were excluded each had a population of zero. Figure 2 shows the locations of certified stroke hospitals and the driving distances to the nearest stroke hospital for each census tract across the contiguous United States.

Urban Tracts

In total, 49 918 (69%) census tracts containing 219 899 221 people were classified as urban (Table 1). The majority of the urban population was under 65 years old (85%), White (68%), non-Hispanic (79%), and medically insured (90%). The population-weighted median of median annual income in all urban census tracts was \$31 027, and the population-weighted median population density was 1481 individuals per square kilometer.

The distribution of distances from urban census tracts to the nearest stroke hospital is shown in Table 2. Increased representations of American Indian or uninsured populations were significantly associated with increased median distance to a stroke hospital, whereas increased representation of Black, Asian, and Other races was associated with decreased median distance to a stroke hospital. There was no statistically discernible association between representation of Pacific Islander population and distance to a stroke center. Each \$10 000 increase in median annual income was associated with a 0.166 km [99.9% CI, 0.104–0.229] increase in median distance to the nearest stroke hospital.

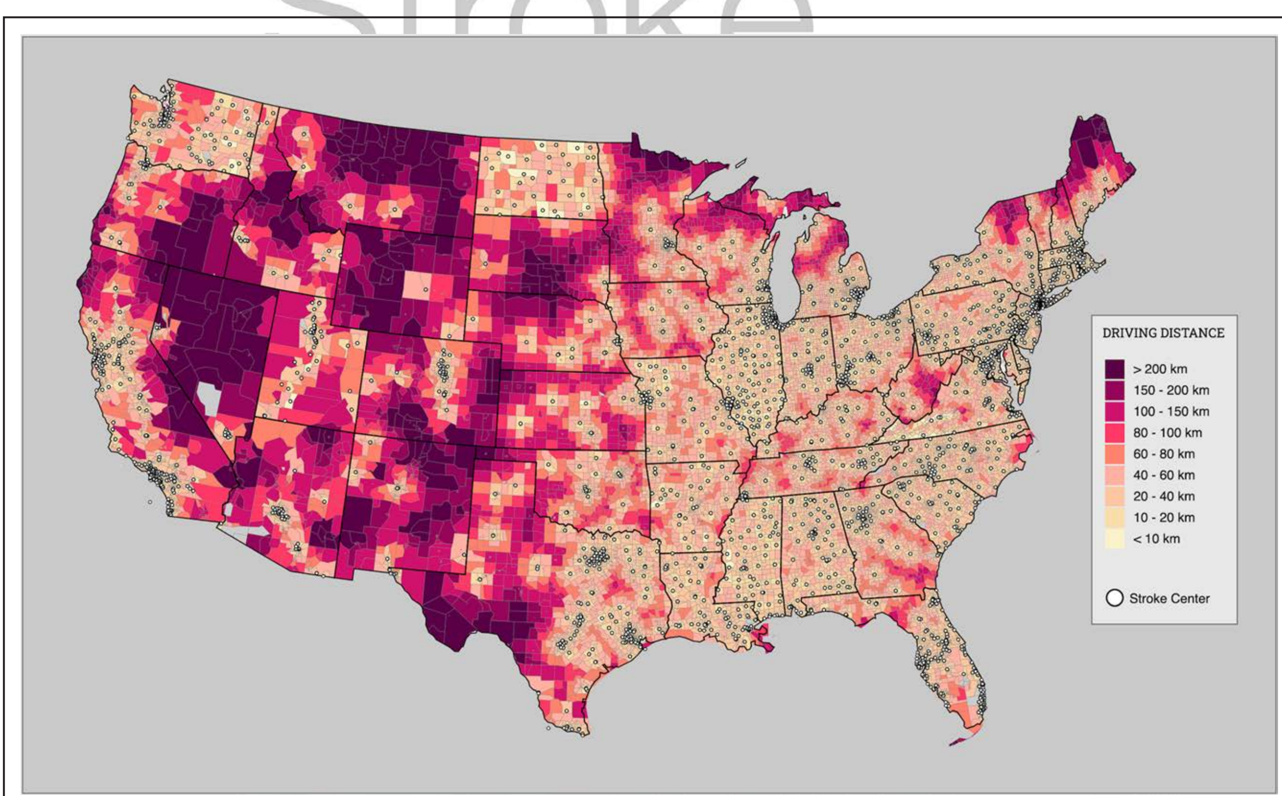

Figure 2. Map of driving distances from census tracts to nearest certified stroke center in the contiguous United States. Gray census tracts had insufficient data (typically populations of zero) and were excluded from analysis.

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Table 1. Population of Selected Demographic Groups in Urban and Nonurban Tracts Within the Contiguous United States

	Urban tracts	Nonurban tracts
Total	219 899 221	97 096 428
Age		
≥65 y	31 895 491 (15%)	17 011 624 (18%)
<65 y	187 993 730 (85%)	80 084 804 (82%)
Race*		
White	149 233 017 (68%)	82 337 084 (85%)
Black	33 009 642 (15%)	7 348 751 (8%)
Asian	15 070 127 (7%)	1 756 058 (2%)
American Indian	1 258 888 (1%)	1 290 904 (1%)
Pacific Islander	350 118 (0%)	75 400 (0%)
Other	20 967 429 (9%)	4 288 231 (4%)
Ethnicity*		
Hispanic	46 880 668 (21%)	9 461 250 (10%)
Not Hispanic	173 008 553 (79%)	87 635 178 (90%)
Annual household income		
<$10 000	27 542 750 (18%)	12 391 671 (18%)
$10 000–14 999	14 959 820 (9%)	7 108 431 (10%)
$15 000–24 999	23 904 901 (15%)	11 161 941 (16%)
$25 000–34 999	19 858 645 (13%)	9 254 276 (13%)
$35 000–49 999	21 132 772 (14%)	9 994 769 (14%)
$50 000–64 999	15 496 153 (10%)	7 034 622 (10%)
$65 000–74 999	6 513 647 (4%)	2 814 907 (4%)
≥$75 000	26 418 756 (17%)	9 521 399 (14%)
Medical insurance		
Insured	198 671 534 (90%)	87 556 364 (91%)
Uninsured	21 069 748 (10%)	8 520 279 (9%)

*Black includes African American, American Indian includes Alaska Native, Pacific Islander includes Native Hawaiian, Other includes other single races or >1 race, and Hispanic includes Latino.

Nonurban Tracts

In total, 22 011 (31%) census tracts containing 97 096 428 people were classified as nonurban (Table 1). The majority of the nonurban population was under 65 years old (82%), White (85%), non-Hispanic (90%), and medically insured (91%). The population-weighted median of median annual income in all nonurban census tracts was $29 058, and the population-weighted median population density was 52 individuals per square kilometer.

The distribution of distances from nonurban census tracts to the nearest stroke hospital is shown in Table 3. Increased representation of age ≥65 years, American Indian, and uninsured populations were significantly associated with increased median distance from a certified stroke hospital, whereas increased representation of Black race was associated with shorter median distance to a stroke hospital. There was no statistically discernible association between representations of Asian and Other races and distance to a stroke center. Each $10 000 increase in median annual income was associated with a decrease of 5.04 km (99.9% CI, 4.31–5.78) in median distance to the nearest stroke hospital.

DISCUSSION

In this work, we quantitatively characterized the association between key demographic characteristics and distance to a certified stroke hospital across the contiguous United States. Our principal findings were (1) people in urban areas were substantially closer to stroke hospitals than people in nonurban areas, (2) demographic factors are associated with proximity to stroke care, and (3) these demographic disparities were markedly more pronounced in nonurban settings.

Disparities in proximity to certified stroke care are important to identify because of their potential clinical impact. Disparities in geographic access can hinder timely treatment of acute ischemic stroke and thus likely translate to disparities in outcome.[26] These disparities in outcome are potentially magnified by the fact that certain population characteristics that may be associated with decreased access to care are also strongly associated with stroke incidence.[27] Efforts to address these disparities through targeted development of stroke care infrastructure and regulatory policy can thus benefit from quantitative assessment of the factors leading to disparate access to stroke care.

Earlier investigations have provided some of these insights. Khan et al[13] found that urban, younger, and higher income groups in North Carolina, South Carolina, and Georgia were more likely to be located within 30-minute and 60-minute driving times to stroke centers. In larger national studies, Adeoye et al[3] reported that 81% of the United States population lived within 60 minutes by ground of a hospital with intravenous thrombolysis, whereas Mullen et al[12] found that 66% of the population lived within 60 minutes of a Joint Commission Primary Stroke Center. Mullen et al[12] also reported improved access to stroke care for non-White and Hispanic populations and reduced access for rural populations. Our work builds on these earlier efforts by more comprehensively incorporating national- and state-level hospital certifications to better capture real-world stroke care infrastructure.[15] Moreover, by defining proximity to care continuously rather than dichotomizing our data on the basis of prespecified time thresholds, we are able to gain quantitative insight into the complete distribution of stroke care access and maintain greater sensitivity to subtle disparities.

Not surprisingly, our study demonstrated markedly greater proximity to certified stroke care in urban areas compared to nonurban areas, congruent with the well-established notion of an urban-rural dichotomy in

Table 2. Distribution of Distance to a Certified Stroke Center Across Census-Defined Demographic Groups Within Urban Tracts in the Contiguous United States

	Distance to stroke center, percentiles				
	10th	25th	50th (median)	75th	90th
Reference tract,* km	2.29	3.77	6.16	10.0	18.7
Change in distance per 1% increase in representation (km; [99.9% CI])					
Age					
≥65 y	0.004 [−0.002 to 0.011]	0.008† [0.001 to 0.015]	0.002 [−0.007 to 0.012]	−0.019† [−0.035 to −0.003]	−0.013 [−0.054 to 0.028]
Race					
Black	0.000 [−0.002 to 0.003]	−0.004† [−0.007 to −0.001]	−0.017† [−0.021 to −0.013]	−0.048† [−0.054 to −0.042]	−0.150† [−0.165 to −0.134]
Asian	0.000 [−0.005 to 0.005]	−0.005 [−0.010 to 0.001]	−0.022† [−0.030 to −0.015]	−0.066† [−0.079 to −0.053]	−0.161† [−0.194 to −0.128]
American Indian	−0.002 [−0.029 to 0.025]	0.013 [−0.018 to 0.044]	0.099† [0.057 to 0.140]	0.489† [0.420 to 0.559]	2.30† [2.13 to 2.48]
Pacific Islander	0.029 [−0.042 to 0.099]	0.053 [−0.027 to 0.134]	0.049 [−0.058 to 0.157]	−0.084 [−0.266 to 0.097]	−0.322 [−0.775 to 0.131]
Other	−0.005 [−0.012 to 0.002]	−0.010† [−0.018 to −0.002]	−0.022† [−0.033 to −0.011]	−0.046† [−0.064 to −0.028]	−0.123† [−0.167 to −0.078]
Ethnicity					
Hispanic	0.008† [0.004 to 0.011]	0.006† [0.002 to 0.010]	−0.002 [−0.007 to 0.003]	−0.025† [−0.034 to 0.016]	−0.096† [−0.119 to −0.073]
Medical insurance					
Uninsured	0.004† [−0.005 to 0.013]	0.010 [0.000 to 0.020]	0.016† [0.002 to 0.029]	0.006 [−0.017 to 0.029]	0.008 [−0.048 to 0.065]
Change in distance per $10 000 increase (km; [99.9% CI])					
Median annual income	0.160† [0.119 to 0.201]	0.172† [0.125 to 0.219]	0.166† [0.104 to 0.229]	−0.136† [−0.241 to −0.031]	−1.67† [−1.93 to −1.41]
Change in distance per 1000 increase in people/km² (km; [99.9% CI])					
Population density	−0.116† [−0.125 to −0.106]	−0.158† [−0.170 to −0.147]	−0.194† [−0.209 to −0.179]	−0.205† [−0.231 to −0.180]	−0.192† [−0.256 to −0.128]

Reference tract distribution indicates the distribution if all tracts were homogeneous; the remaining distributions indicate changes in the overall distribution arising from changes in underlying characteristics.

*Reference tract is a hypothetical urban tract with typical composition of 15% age ≥65 y, 15% Black, 7% Asian, 1% American Indian, 0% Pacific Islander, 9% Other, 21% Hispanic, and 10% uninsured, with median annual income of $31 027 and population density of 1481 individuals per square kilometer.

†P<0.001.

treatment availability.[10,28,29] Beyond actual differences in geographic proximity to stroke care between urban and nonurban tracts, our analysis found remarkable differences in both magnitude and direction of the associations between demographic characteristics and stroke care proximity in urban and rural settings. For example, our analysis revealed that increased median annual income was weakly associated with greater median distance to stroke care in urban areas but strongly associated with decreased distance in nonurban areas. Explanations for piecewise trends such as these include not only the nonuniform distribution of demographic subgroups, such as concentration of higher income groups in suburban areas on the periphery of urban areas, but also differences in infrastructure, including more numerous hospitals and higher density road networks in urban areas. Regardless of cause, trends that are nonlinear across the urban-rural spectrum are more likely to be piecewise quasilinear across the urban-suburban spectrum and suburban-rural spectrum. These differences were a primary motivation for using analyzing urban and nonurban tracts separately.

Among urban tracts, our data indicate that increasing representation of Black, Asian, and Other race groups is associated with very slightly reduced median distance to a stroke center, whereas increasing representation of American Indian or uninsured populations is associated with very slightly increased median distance to a stroke center. Similarly, tracts with greater median annual income are associated with slightly increased median distance to a stroke center, whereas tracts with higher population density are associated with slightly decreased median distance to a stroke center.

Our data reveal more pronounced demographic disparities in geographic proximity to stroke care among nonurban tracts. These trends ostensibly reflect the relatively greater geographic dispersion of the nonurban

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Table 3. Distribution of Distance to a Certified Stroke Center Across Census-Defined Demographic Groups Within Nonurban Tracts in the Contiguous United States

	Distance to stroke center, percentiles				
	10th	25th	50th (median)	75th	90th
Reference tract,* km	12.0	18.3	30.2	50.1	80.1
Change in distance per 1% increase in representation (km; [99.9% CI])					
Age					
≥65 y	−0.032 [−0.076 to 0.012]	0.086† [0.035 to 0.140]	0.506† [0.421 to 0.592]	1.55† [1.40 to 1.71]	2.62† [2.30 to 2.94]
Race					
Black	−0.075† [−0.097 to −0.054]	−0.121† [−0.147 to −0.095]	−0.196† [−0.238 to −0.154]	−0.322† [−0.399 to −0.245]	−0.502† [−0.659 to −0.346]
Asian	−0.165 [−0.253 to −0.078]	−0.174† [−0.282 to −0.066]	−0.133 [−0.304 to 0.039]	−0.105 [−0.421 to 0.211]	0.267† [−0.373 to 0.908]
American Indian	0.210† [0.171 to 0.249]	0.465† [0.417 to 0.513]	1.06† [0.98 to 1.13]	1.60† [1.46 to 1.74]	2.26† [1.97 to 2.54]
Pacific Islander	0.119 [−0.752 to 0.990]	0.159 [−0.917 to 1.234]	0.710 [−0.999 to 2.418]	1.94 [−1.21 to 5.09]	6.98† [0.60 to 13.35]
Other	−0.057 [−0.130 to 0.015]	−0.042 [−0.132 to 0.047]	−0.126 [−0.268 to 0.017]	−0.282† [−0.544 to −0.020]	−0.100 [−0.630 to 0.430]
Ethnicity					
Hispanic	−0.009 [−0.036 to 0.018]	−0.012 [−0.045 to 0.022]	0.037 [−0.016 to 0.090]	0.308† [0.211 to 0.405]	0.834† [0.637 to 1.031]
Medical insurance					
Uninsured	0.097† [0.040 to 0.155]	0.156† [0.085 to 0.227]	0.267† [0.153 to 0.380]	0.233† [0.024 to 0.442]	−0.029 [−0.452 to 0.394]
Change in distance per $10 000 increase (km; [99.9% CI])					
Median annual income	−0.231 [−0.606 to 0.145]	−1.66† [−2.13 to −1.20]	−5.04† [−5.78 to −4.31]	−8.86† [−10.22 to −7.50]	−12.0† [−14.7 to −9.2]
Change in distance per 1000 increase in people/km†(km; [99.9% CI])					
Population density	−23.9† [−24.5 to −23.2]	−26.8† [−27.6 to −26.0]	−18.7† [−20.0 to −17.4]	−4.62† [−6.93 to −2.32]	−4.95† [−9.61 to −0.28]

Reference tract distribution indicates the distribution if all tracts were homogeneous; the remaining distributions indicate changes in the overall distribution arising from changes in underlying characteristics.

*Reference tract is a hypothetical nonurban tract with typical composition of 18% age ≥65 y, 8% Black, 2% Asian, 1% American Indian, 0% Pacific Islander, 4% Other, 10% Hispanic, and 9% uninsured, with median annual income of $29 058 and population density of 52 individuals per square kilometer.

†*P*<0.001.

population, which has the effect of magnifying demographic disparities in proximity to certified stroke care. Among nonurban tracts, increasing representation of elderly, American Indian, or uninsured populations was associated with considerably longer median distance to a stroke center, while increasing representation of a Black population, greater median annual income, and higher population density are associated with considerably shorter median distance to a stroke center. These results are clinically important not only just for the sheer magnitude of demographic disparity in nonurban tracts but also because many demographic groups with reduced proximity to certified stroke care, such as the elderly, uninsured, and American Indian populations, also have generally higher stroke incidence or face additional barriers to care besides distance.[30–32] Efforts to address disparities in these at-risk populations may thus be particularly effective in elevating access to stroke care nationwide.

Although our analysis shows that demographic disparities are more pronounced in nonurban than urban areas, we must highlight that urbanicity itself is perhaps the largest source of disparity in proximity to stroke care. Our reference tract distribution indicates that nonurban areas are 5 to 6× further from stroke care than urban areas. This disparity may reflect the historical preference for urban and more profitable hospitals in the stroke certification process.[6,15] Regardless of cause, this enormous disparity adversely impacts care of the nearly 100 million Americans that reside in nonurban areas. Recognizing the need for acute stroke care in all settings, the current system of stroke center certification includes acute stroke-ready hospitals. These hospitals are intended to enhance access to basic stroke care in small cities and rural areas and provide a portal for transfer to higher levels of stroke care when needed.[33] However, our results demonstrate disparities in proximity to stroke care even with acute stroke-ready hospitals currently in existence.

To reduce this location-based penalty, certifying bodies must continue to encourage development and certification of stroke centers in nonurban areas and emphasize return on investment in terms of health benefits to citizens rather than financial benefits to hospitals. Simultaneously, state legislatures can work to develop more integrated and coordinated systems of care that can more rapidly triage and transfer nonurban patients with stroke to the most appropriate stroke center. State-level stroke legislation of this form has been shown to improve access to stroke care.[15]

Our use of quantile regression is noteworthy. Similar to multivariate linear regression, multivariate quantile regression controls for potential confounding between predictors. However, unlike conventional multilinear regression, quantile regression provides regression analysis of an entire distribution. This approach makes no assumptions about the underlying data distribution, rendering it less sensitive to outliers and better able to offer insight into data like ours with non-normal distributions.[25,34] Additionally, the uncertainties of the resulting estimates provide a measure of sensitivity. These features make quantile regression a fixture of econometric and other complex social analyses.[25,35] The importance of a quantile regression approach in our analysis is highlighted by the observed variability of regression estimates for key demographics at different percentiles. This variability would not be apparent in a multilinear regression model that provides a single description of the relationship rather than a spectrum of change across the entire distribution.

There are several limitations to our results. First, our list of stroke hospitals was compiled in part by manual exploration of individual state government websites. Although this represents an improvement to hospital lists drawn only from national organizations, it still may not completely capture available stroke care infrastructure. Second, our study utilizes travel distance rather than travel time as a measure of proximity to care. Although distance has the clear analytic advantage of being constant and well-defined throughout the diurnal cycle, travel time may provide more clinically relevant insight, especially in heavily congested urban areas. Additionally, defining a meaningful distance threshold is difficult given the variable relationship with travel time. Third, demographic characteristics are aggregated at the census tract level. Disaggregated data at the level of the individual would allow more robust study of the relationship between demographic variables and hospital distance. Fourth, our analysis does not account for nearest hospital bypass policies that may be in place in some jurisdictions.

CONCLUSIONS

In conclusion, we have quantified national disparities in proximity to certified stroke care based on age, race, ethnicity, insurance, income, and population density. The most significant disparities in proximity to certified stroke care occurred in nonurban areas with high representation of age ≥65 years, American Indian, or medically uninsured populations, low median annual income, and low population density. Disparities and overall proximity to stroke care were considerably worse in nonurban areas than in urban areas. Rigorously quantifying disparities in proximity to timely and life-saving stroke care can bolster efforts to implement infrastructure improvements. Future research is needed to correlate disparities in proximity to stroke care with clinical outcomes.

ARTICLE INFORMATION

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