Contents lists available at ScienceDirect

Journal of Stroke and Cerebrovascular Diseases

journal homepage: www.elsevier.com/locate/jstroke

Navigating stroke care: Geospatial assessment of regional stroke center accessibility
Geospatial Assessment of Stroke Centers

Stephen Halada, BS [a,*], Kirsten MM Beyer, PhD, MPH [b], Yuhong Zhou, PhD [b], Benjamin W Weston, MD, MPH [c]

[a] *Medical Student, Medical College of Wisconsin, Milwaukee, WI, 53226, USA*
[b] *Institute for Health & Equity, Medical College Wisconsin, 8701 W Watertown Plank Rd, Milwaukee, WI, 53226, USA*
[c] *Department of Emergency Medicine, Medical College Wisconsin, 8701 W Watertown Plank Rd, Milwaukee, WI, 53226, USA*

ARTICLE INFO

Keywords:
Geospatial analysis
Public health
Accessibility
Cardiovascular/stroke

ABSTRACT

Introduction: Reducing time between stroke onset and hospital intervention is crucial for positive outcomes in stroke patients. While EMS utilization decreases time to intervention, many US regions are not within timely proximity to an advanced-care-capable stroke center (ASC), defined as a comprehensive or thrombectomy-capable center. This study aims to utilize geographic methodology to identify regions in Wisconsin with both high stroke mortality and low physical accessibility to certified stroke centers (SCs), particularly ASCs.
Methods: Geocoded mortality records for stroke death between 2015 and 2020 were accessed from the Wisconsin Department of Health Services. Indirectly age-standardized mortality ratios (SMRs) were estimated continuously across Wisconsin using adaptive spatial filtering and mortality records at the census block group level; the surface was then averaged by census tract for tract level SMRs. Addresses for SC locations within Wisconsin and bordering states were collected, and drive times from Wisconsin census tract centroids to the nearest SC subtypes were estimated. Drive times and mortality ratios were evaluated at the tract level alongside Rural-Urban Commuting Area (RUCA) codes. Spatial error regression modeling was used to determine RUCA classifications with the highest stroke risk independent of accessibility to stroke centers.
Results: Approximately 50%, 68%, and 78% of Wisconsin residents resided within 30, 45, and 60 minutes of an ASC, respectively. Median drive time from census tract centroids to the nearest ASC were highest for rural tracts (M=90 minutes, IQR=68-115) compared to small-town (M=82 minutes, IQR=49-113), micropolitan (M=53 minutes, IQR=43-77), and metropolitan tracts (M=19 minutes, IQR=11-35; $p<0.001$). Clusters of high stroke SMRs were found in urban centers as well as rural areas irrespective of county declinations. Spatial regression modeling suggested small-town census tracts had the highest SMR irrespective of physical accessibility to care and spatial correlation. In small-town census tracts >45 minutes from the nearest ASC, the median stroke SMR was 1.12 (IQR=0.94-1.40) with 226,000 residents and 150 stroke deaths per year.
Conclusion: Small-town areas are associated with both long drive distance to ASC locations and high stroke mortality. Geographical analyses reveal apparent stroke care deserts and may inform strategic allocation of emergency medicine resources and coverage.

Introduction

Cerebrovascular accidents, also known as strokes, are significant contributors to the overall cardiovascular disease burden and require timely and, often, specialized interventions[1]. Various medical interventions are available for acute stroke management including

Abbreviations: SC, Certified Stroke Center; ASC, Advanced-Care-Capable Stroke Center; ASRH, Acute Stroke Ready Hospital; PSC, Primary Stroke Center; TSC, Thrombectomy-Capable Stroke Center; CSC, Comprehensive Stroke Center; RUCA, Rural-Urban Commuting Area; CMR, Crude Mortality Rate; SMR, Standardized Mortality Ratio; ASF, Adaptive Spatial Filtering.

* Corresponding author.
E-mail addresses: shalada@mcw.edu (S. Halada), kbeyer@mcw.edu (K.M. Beyer), yuzhou@mcw.edu (Y. Zhou), beweston@mcw.edu (B.W. Weston).

https://doi.org/10.1016/j.jstrokecerebrovasdis.2024.108093
Received 30 July 2024; Received in revised form 15 September 2024; Accepted 15 October 2024
Available online 24 October 2024

thrombolytic therapy, mechanical thrombectomy, and neuroendovascular procedures. Minimizing the time between stroke symptoms and definitive medical interventions is crucial for optimizing neurocognitive ability and achieving overall positive outcomes. Thus, stroke management and equitable access to care remain emergency medicine and public health challenges.

Timely delivery of these critical emergency interventions is dependent on availability and accessibility of certified stroke centers (SCs) that are equipped to provide care for varying levels of stroke severity. SCs are classified and certified by scope of available on-site interventions and, therefore, their ability to treat increasing levels of stroke severity. Center classifications based on the Joint Commission certification include acute stroke ready hospital (ASRH), primary stroke center (PSC), thrombectomy-capable stroke center (TSC), and comprehensive stroke center (CSC)[2]. Of these, TSCs and CSCs are equipped to administer mechanical thrombectomy intervention and other advanced stroke treatment options critical for large vessel occlusive strokes and severe hemorrhagic strokes, respectively[3, 4]. These centers also are critical for maintaining the capabilities of lower-level stroke centers. However, access to SCs is not uniformly distributed across geographical regions, and advanced-care-capable centers (ASCs) are generally less uniformly distributed compared to basic centers[5].

While the annual stroke death rate has trended downward over the past several decades, stroke mortality rates vary by geography, and many regions of the United States lie outside of timely proximity to SCs[6-9]. These disparities are amplified when considering access to advanced care with non-urban areas facing the greatest stroke center accessibility challenges[6-10]. Furthermore, large vessel occlusions account for 96.5% of stroke deaths despite comprising of 38.7% of total strokes[11]. Although almost one-third of stroke cases could potentially benefit from advanced interventions (i.e. mechanical thrombectomy or other neuroendovascular procedure), just over 3% receive mechanical thrombectomy, likely due in part to access challenges[12].

Given the importance of physical accessibility to stratified stroke care, previous studies have employed geographical analyses to investigate stroke center accessibility in relation to factors such as population coverage, emergency medical service networks, and rural status[8]. In this study, we aimed to highlight gaps in accessibility to stroke center subtypes in the state of Wisconsin while considering regional disparities in stroke mortality. Ultimately, we hope these findings will add to a growing body of literature of geographical methodology applied to stroke-related public health and impact state policy regarding regions with high stroke mortality and low stroke center coverage.

Methods

This ecological study utilized 2015-2020 mortality data from the Wisconsin Department of Health Services and geographical data from the 2010 US census. Adaptive spatial filtering (ASF) allowed calculation of local stroke mortality rates/ratios and visualization across a continuous map. Mortality was estimated by surface area for all Wisconsin census tracts to allow for comparison of census tract-level variables. Mann Whitney U, Kruskal-Wallis, and spatial error regression modeling were used to statistically compare regional census tract factors and associate those factors with high local stroke mortality.

Data sources and census tract-level covariates

All mortality records in the state of Wisconsin between 2015 and 2020 were accessed from the Wisconsin Department of Health Services. Mortality records include an immediate cause of death, conditions leading to the cause of death, and demographic information. Residential address, age at death, sex, race and ethnicity, and education level for each mortality record were used for this study. Race and ethnicity information are reported via an informant – spouse, parent, child, or other relative – or via coroner observation if an informant is unavailable[13]. Stroke deaths were defined using *International Classification of Disease 10th Revision (ICD-10)* codes I60-69; all stroke classifications were included to evaluate geographical trends irrespective of mechanism of cerebral vascular injury. Mortality records in which stroke was identified as the immediate cause of death or as a contributing factor were selected[14].

Census tract-level variables – Rural-Urban Commuting Area (RUCA) codes and minimum drive time to nearest stroke center – were abstracted or estimated, respectively. RUCA codes from the 2010 US census were accessed and matched to respective Wisconsin census tracts[15]. Census tracts were further defined into metropolitan, micropolitan, small-town, or rural as well as urban (metropolitan) or rural (micropolitan, small-town, and rural) classifications according to the RUCA coding definitions[15]. Certified stroke center (SC) information in Wisconsin and surrounding states within 50 drive miles of state borders were collected from the Joint Commission, DNV Healthcare, and Accreditation Commission for Health Care. SCs were classified as a CSC, TSC, PSC, or ASRH according to the Joint Commission definitions[2]; centers were further classified as advanced-care-capable, which included TSC and CSCs. After obtaining SC geographic coordinates, drive time analyses were conducted via Mapbox API, which provides an interface in R software to calculate drive times between matrices of coordinates. In this study, this interface was used to calculate minimum drive time from census tract centroids to the closest SC for each Wisconsin census tract.

SC catchment areas were estimated for locations within 30, 45, and 60 minutes of SC locations via HERE API, which provides an interface in R software to create integrated catchment maps for a matrix of coordinates. Population estimates within SC catchment areas were calculated using the proportion of catchment overlap with census tracts and 2018 census tract population estimates from the American Community Survey[16].

Mortality data cleaning and preparation

Extracted stroke mortality records were examined and cleaned to ensure data quality. Residential addresses were geocoded using Melissa Data services; coordinates localized to the community-, street-, or interpolated-roof level were examined manually for accuracy. Of the 14,885 records of stroke death, 14,671 records were successfully geocoded (98.6%).

Mortality ratio calculations

Crude mortality rates (CMRs) and standardized mortality ratios (SMRs) for stroke were estimated continuously across Wisconsin. CMR measures mortality incidence for a given population, and SMR standardizes this rate against expected rates for age and sex groupings. For stroke SMR, indirect age adjustment was selected given instability of local small area rates, which complicates direct age adjustment. Observed cases at the census block group level were divided by the expected number of cases for each block group, which were calculated using sex and 10 age categories – 18-44, 45-49, 50-54, 55-59, 60-65, 65-69, 70-74, 75-79, 80-84, and 85 or over. Adaptive spatial filtering (ASF) – a technique which aims to control local population bases for calculating rates and provide detailed continuous depictions of those rates – was deployed in R software to create continuous surface maps[17]. In this method, a grid of estimation points is used to calculate SMRs by sourcing data around the estimation point until a pre-defined threshold is met. In this study, thresholds of 20, 30, 40, and 50 observed stroke deaths were tested to explore threshold impact on regional patterns versus smoothness; a threshold of 30 observed deaths best balanced these factors. Inverse distance weighting with a power of 2 was used to interpolate these points to generate a continuously defined surface of the crude stroke mortality rate and indirectly age- and sex-adjusted stroke SMRs across the state. SMRs for census tracts were then estimated by averaging census tract surface areas from the continuously defined stroke SMR map.

Statistical analysis

Stroke mortality and regional variables were summarized using non-parametric descriptive statistics. SMR was used throughout these analyses to capture regional stroke mortality adjusted for sex and age. Continuous variables were compared using two-tailed Mann Whitney U and Kruskal-Wallis tests with post hoc multiple pairwise comparisons. Spatial error regression modeling, which is preferred over traditional regression for its ability to accommodate autocorrelation that is inherent in spatial data, was used to evaluate RUCA classifications most associated with high SMR independent of spatial dependencies and stroke center drive times.

Results

Certified stroke centers and population coverage

As of September 2023, there were 56 SCs in the state of Wisconsin including 32 PSCs, 16 ASRHs, 1 TSC, and 7 CSCs. All advanced-care-capable stroke centers (TSCs and CSCs) and the majority (54%) of basic stroke centers (PSCs and ASRHs) were located in metropolitan census tracts. Additionally, 63 SCs in the surrounding states of Iowa, Minnesota, and Illinois were within 50 drive miles of the Wisconsin border. There were no certified SCs in Michigan within 50 drive miles; however, four care centers in Michigan's upper peninsula were members of the Michigan stroke program but were excluded due to lack of SC certification. Taken together, there were a total of 119 SCs in Wisconsin and surrounding areas including 70 PSCs, 18 ASRHs, 3 TSCs, and 28 CSCs.

Catchment zones by 30-, 45-, and 60- minute drive time for SCs are visualized in Fig. 1 with separate breakdown for basic and advanced-care-capable stroke center catchment. Gaps in coverage by drive time were found primarily in northern and southwestern Wisconsin and were particularly prominent for ASCs. For population coverage, 83.5%, 92.2%, and 97% of Wisconsin residents lived with 30, 45, and 60 minutes, respectively, of a SC (Table 1). Greater percentages of the Wisconsin population were within drive distance to a basic stroke center compared to ASCs (Table 1). Similarly, census tract drive times to the nearest basic stroke center (M=15 minutes, IQR=8-33) were shorter than to the nearest ASC (M=32 minutes, IQR=14-62, W=1307317, $p<0.001$, Table 1). Median drive time from census tract centroids to the nearest ASC were highest for rural tracts (M=90 minutes, IQR=68-115) compared to small-town (M=82 minutes, IQR=49-113), micropolitan (M=53 minutes, IQR=43-77), and metropolitan tracts (M=19 minutes, IQR=11-35; Kruskal-Wallis χ^2= 631.42, $p<0.001$). These accessibility challenges were particularly accentuated for small-town (M=82 minutes, IQR=49-113) and rural census tracts (M=90 minutes, IQR=68-115). Furthermore, 48% of small-town and rural census tracts were >45 minutes from the nearest SC, and 89% were >45 minutes from the nearest ASC.

Stroke mortality distribution in wisconsin

Between 2015 and 2020, 14,671 deaths were attributed to stroke in Wisconsin with an average of 2,934 stroke deaths per year (approximately 50 per 100,000). The majority of this cohort was female (60%) and non-Hispanic White (91%) with a median age at death of 85 (IQR=75-91). Residential census tracts were primarily urban (66%) with a median minimum drive time to the nearest SC of 14 minutes (IQR=8-26). However, for residents living in non-metropolitan census tracts, the median minimum drive time was 35 minutes (IQR=21-52). Similarly, despite generally low drive times to any SC, 39% of the cohort lived >45 minutes to the nearest ASC. This subset resided in more rural communities, included a higher proportion non-Hispanic White, and received generally less education than people who lived in census tracts <45 minutes to the nearest ASC (Table 2).

Geographical variations in stroke mortality crude rate and standardized ratio are depicted in Fig. 2. Distinct clusters of high stroke mortality were found in rural and urban regions irrespective of county delineations. Considering census tracts with high stroke mortality, 358 census tracts with approximately 1,350,000 residents (23% WI population) had an SMR above 1.25 (75th percentile for SMR in Wisconsin); 32% of these residents lived in micropolitan, small-town, or rural census tracts with a median drive time of 35 minutes (IQR=21-52) to the nearest SC and 73 minutes (IQR=49-106) to the nearest ASC.

Identification of stroke coverage gaps and high stroke mortality

Rural census tracts had the highest absolute stroke SMR (M=1.06, IQR=0.9-1.27) compared to metropolitan (M= 1.02, IQR= 0.87-1.26), micropolitan (M= 1.05, IQR= 0.89-1.26), and small-town (M= 1.05, IQR= 0.89-1.24, Kruskal-Wallis χ^2=25.729, $p<0.001$). Among small-town and rural census tracts with high stroke mortality (SMR>1), 274,000 residents (5% of WI population) were >45 minutes from the nearest SC, accounting for 200 stroke deaths per year. For ASCs, 500,000 (9% of WI population) residents in these areas were >45 minutes from the nearest ASC, accounting for 370 stroke deaths per year. These regional coverage gaps with census tract standardized mortality rates are visualized in Fig. 3.

A spatial error model was used to determine the census tract RUCA classification with the highest stroke SMR independent of center

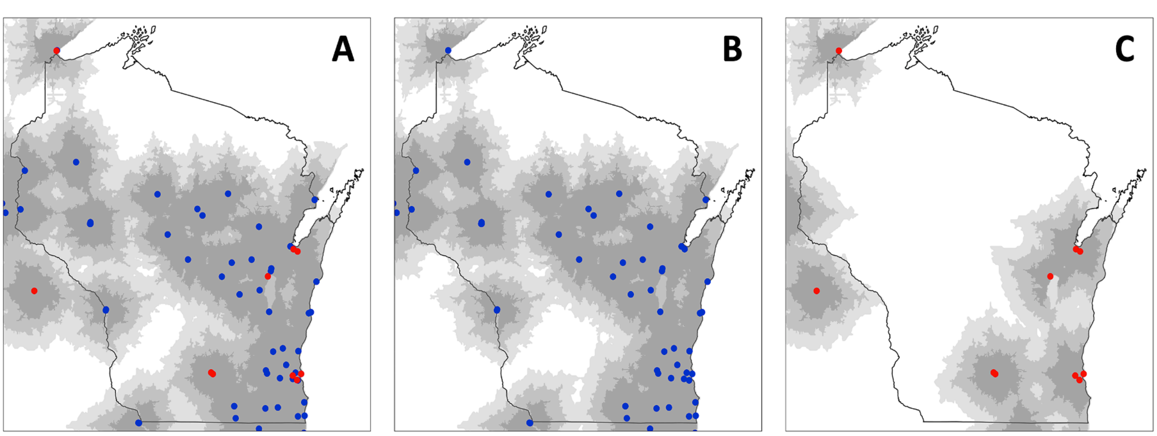

Fig. 1. Drive catchment zones by 30-, 45-, and 60-minute estimations for **(A)** certified stroke centers, **(B)** basic centers (blue), and **(C)** advanced-care-capable centers (red).

Table 1
Demographics and stroke coverage by stroke center certification.

	Stroke Centers (SCs)	Basic Stroke Centers			Advanced-Care-Capable Stroke Centers		
	n=119	PSC n=70	ASRH n=18	Total Basic n=88	TSC n=3	CSC n=28	Total ASC n=31
Minimum Drive Time from Census Tract Centroid to SC, *median (IQR)*	13 (8-25)	17 (9-44)	40 (31-50)	15 (8-33)	86 (74-116)	34 (15-65)	32 (14-62)
Urban							
Metropolitan	10 (7-16)	11 (7-19)	39 (32-45)	11 (7-18)	83 (73-106)	20 (11-36)	19 (11-35)
Non-urban	35 (21-52)	49 (34-71)	46 (27-74)	35 (21-54)	111 (78-151)	76 (52-111)	73 (49-106)
Micropolitan	23 (13-31)	34 (26-46)	39 (32-52)	23 (13-31)	104 (56-142)	57 (46-79)	53 (43-77)
Small-town	39 (22-44)	52 (39-74)	57 (23-78)	39 (22-60)	113 (85-162)	91 (49-127)	82 (49-113)
Rural	46 (34-60)	65 (49-85)	55 (38-90)	46 (34-62)	115 (86-164)	95 (70-127)	90 (68-115)
Population, *% (total estimate)*							
30-minute drive time	83.5	66.0	32.8	74.7	9.8	49.0	50.4
45-minute drive time	92.2	83.1	74.6	87.9	15.7	66.9	68.3
60-minute drive time	96.8	92.4	86.5	95.4	23.8	76.6	77.6
Stroke SMR of Census Tracts							
<30-minute drive time	1.06 (0.90-1.26)	1.09 (0.94-1.31)	1.06 (0.94-1.25)	1.08 (0.93-1.29)	0.85 (0.71-0.99)	1.05 (0.89-1.25)	1.04 (0.87-1.24)
30-45-minute drive time	1.02 (0.87-1.19)	1.02 (0.85-1.17)	1.08 (0.92-1.33)	1.00 (0.86-1.14)	1.12 (0.98-1.32)	1.13 (0.97-1.37)	1.14 (0.98-1.39)
45-60-minute drive time	1.03 (0.88-1.28)	0.95 (0.77-1.12)	0.95 (0.80-1.12)	0.90 (0.75-1.08)	1.15 (0.93-1.32)	1.09 (0.97-1.37)	1.08 (1.00-1.29)
>60-minute drive time	1.03 (0.84-1.10)	0.98 (0.84-1.20)	1.05 (0.90-1.30)	1.05 (0.90-1.29)	1.07 (0.91-1.27)	1.01 (0.85-1.17)	1.01 (0.86-1.18)

Abbreviations: SC, certified stroke center; *PSC*, primary stroke center; *ASHR*, acute stroke ready hospital; *TSC*; thrombectomy-capable stroke center; *ASC*; advanced-care-capable stroke center.
Basic centers include PSCs and ASRHs; advanced-care-capable stroke centers (ASCs) include TSCs and CSCs.

accessibility and spatial autocorrelation. Small-town census tracts were associated with the highest stroke SMR independent of proximity to a basic, advanced-care-capable, or any certified stroke center (z=4.4073, $p<0.001$; model Wald statistic= 5967.1, $p<0.001$). In small-town census tracts >45 minutes from the nearest ASC, the median stroke SMR was 1.12 (*IQR*=0.94-1.40) with 226,000 residents and 150 stroke deaths per year.

Discussion

In this study, we demonstrated significant gaps in direct stroke care coverage – especially advanced stroke care – for large segments of Wisconsin, including areas with high standardized stroke mortality. Several studies have demonstrated disparities in population-level stroke care access by geography, place of residence, rural/urban status, and community demographics[5, 9, 18, 19]. However, to our knowledge, this is the first study evaluating both basic and advanced-care-capable stroke center access for an entire state while considering geographical risk for stroke mortality. These findings have implications for emergency stroke intervention coverage in Wisconsin, such as prioritizing greater advanced care access for specific high-mortality regions, while providing a methodology for other states and regions to perform a similar evaluation.

While a 2011 study demonstrated significant coverage gaps for primary stroke center (PSC) access in the southeastern United States, including high stroke mortality in many counties without adequate access, stratification in stroke center capacity and ability was not performed[9]. More recently, large gaps to thrombectomy and advanced care services were highlighted in eleven US states, demonstrating that this is a widespread issue[8]. While geographical patterns in stroke mortality – as in all health outcomes data – are dynamic, considering coverage gaps for regions with highest apparent risk may represent an effective strategy to address the logistical challenges of increasing statewide emergency and advanced care access[20].

In the state of Wisconsin specifically, Richland, Sauk, Iowa, Rusk, Bayfield, Ashland, and Iron counties demonstrated the highest stroke mortality with suboptimal access to emergency stroke intervention. When considering advanced care, greater proportions of the population at risk for stroke mortality were without direct access to thrombectomy and other advanced procedures compared to basic stroke services (Fig. 3). Regression analyses demonstrated that small-town census tracts had the highest stroke mortality rates. Thus, focusing on improving access to these areas with limited coverage may represent a viable strategy for emergency stroke care allocation. Furthermore, while inferring causality is not appropriate in this case, our results suggest that regional stroke mortality rates are substantially associated with local region and population characteristics in addition to physical proximity to a SC, which have increased in numbers over the past decade[21-23]. These findings highlight the complicated influence of geographical and regional variation on health outcomes and underscore the importance of collaborating with local communities and emergency health networks to optimize population health. While these results have immediate generalizability to the state of Wisconsin, different geographical regions each have their own unique populations and factors, necessitating similar methodology to be employed on a state-by-state or region-by-region basis.

Widespread and equitable expansion of emergency stroke services is logistically and financially challenging. The hub-and-spoke model to stroke care delivery has been popularized over the past decade in attempts to balance population coverage of essential stroke services with the expenses of staffing fully comprehensive stroke sites. This is typically achieved by prioritizing thrombolytic capability of geographically distributed spoke sites that initiate transfer to central hub sites for advanced services, which takes pressure off hub sites while expanding timely life-saving interventions to the broader community[24]. In certain communities, adoption of such models has been accompanied by a 33%

Table 2
Cohort demographics by residential proximity to advanced-care-capable stroke center.

	Total Cohort n=14671	Residential Census Tract <45 min to ACC center n=8889 (61%)	Residential Census Tract >45 min to ACC center n=5782 (39%)	*P-value*
Demographic characteristics				
Age, median (IQR)	85 (75-91)	84 (74-91)	85 (76-91)	**<0.001**
Sex, n (%)				
Female	8750 (59.6)	5243 (59.0)	3507 (60.7)	**0.046**
Male	5921 (40.4)	3646 (41.0)	2275 (39.3)	
Race/Ethnicity, n (%)				
Non-Hispanic White	13616 (92.8)	7969 (89.7)	5647 (97.7)	*<**0.001**
Non-Hispanic Black	718 (4.9)	698 (7.9)	20 (0.3)	
Hispanic	217 (1.5)	194 (2.2)	23 (0.3)	
*Other	120 (0.8)	28 (0.3)	92 (1.6)	
Education, n (%)				
High school only or less	9743 (66.4)	5655 (63.6)	4088 (70.7)	†**<0.001**
Some college	1453 (9.9)	916 (10.3)	537 (9.3)	
Associate degree	1077 (7.3)	671 (7.5)	406 (7.0)	
Bachelor's degree	1451 (9.9)	988 (11.1)	463 (8.0)	
Postbaccalaureate	757 (5.2)	535 (6.0)	222 (3.8)	
UNK	190 (1.3)	124 (1.4)	66 (1.1)	
Residential census tract characteristics				
Urban status, n (%)				
Urban				‡**<0.001**
Metropolitan	9671 (65.9)	7911 (89.0)	1760 (30.4)	
Rural	5000 (34.1)	978 (11.0)	4022 (69.6)	
Micropolitan	1802 (12.3)	548 (6.2)	1254 (21.7)	
Small-town	1887 (12.9)	395 (4.4)	1492 (25.8)	
Rural	1311 (8.9)	35 (0.4)	1276 (22.1)	
Residential Census Tract to SC, *median (IQR)*	14 (8-26)	11 (7-16)	27 (13-48)	**<0.001**

Abbreviations: ACC; advanced-care-capable.
Other races include American Indian, Laotian/Hmong, Other Asian, Other Race, and Multi-race as defined by the state of Wisconsin.
Statistics: χ^2 for categorical variables, two-tailed Mann Whitney U for continuous variables, ***p-value* < 0.05 statistically significant**.
* non-Hispanic white vs. others.
† high school or less vs. others.
‡ urban vs. rural.

increase in interhospital stroke transfers from 2009 to 2014 resulting in an increase in thrombolytics for rural stroke patients where direct access to higher level stroke centers may be lacking[25]. However, access to advanced services remains a significant barrier for large parts of the US population, even accounting for interhospital transfers[8]. Additionally, thrombectomy has proven extremely effective in recent years for recanalizing large vessel occlusions[26], while studies have shown mixed efficacy for thrombectomy preceded by thrombolysis, which would have otherwise represented a viable solution for regions without access to ASCs[27]. Taken together, reducing coverage gaps to advanced emergency interventions for small-town and rural communities must be prioritized in prehospital and emergency stroke management.

Several evidence-based policies have been impactful for addressing these disparities in other regions, including improvements in large vessel occlusion detection[28], implementation of telestroke and mobile stroke unit capabilities[7, 29], and optimization of interhospital transfers[4]. In recent years, recommendations for regional stroke designation guidelines have focused on utilizing large vessel occlusion scales for stratifying prehospital approaches stroke of varying severity[30]. Expansion of advanced stroke services based on geographical gaps and mortality risk, as highlighted in this study, offers promise for improving stroke outcomes. For Wisconsin, this strategy would favor advanced certification status for at least two additional hub sites in southwestern and northern areas of the state, respectively, where stroke mortality is relatively high and access to stroke care is inadequate. With this policy, more residents living in high-risk regions would be in proximity to comprehensive care rather than to spoke sites.

The results of this study must be considered alongside limitations. While this study made use of comprehensive state mortality data geocoded to residential address, inferring a correlation with stroke incidence and location of the cerebral vascular event is not appropriate. Additionally, the methodology of this study was constructed with consideration for the available state-wide mortality records; while much of our discussion focused on large vessel occlusions as an area of opportunity, the study at large included all stroke events to evaluate complete stroke burden. Similarly, real-time clinical data, such as large vessel occlusion evaluation in the field and other in-hospital parameters, were unavailable. Finally, accessibility analyses in this study focused on direct drive accessibility and did not account for helicopter flight times or potential hospital transfers as mentioned above. Future analyses may benefit from integrating more detailed information regarding the dynamics and capabilities of hospital transfer networks as well as additional quantified geographical and community level variables of interest.

Conclusion

This study contributes to a growing body of literature supporting the utilization of various geographical methods for addressing the public health impact of stroke on regional communities. Our results demonstrate highly variable stroke mortality rates by geography as well as high stroke mortality and low physical accessibility to basic and advanced-care-capable stroke centers in small-town census tracts in Wisconsin. These findings may inform strategic state allocation of EMS and emergency department resources and coverage in Wisconsin, and the methodologies herein may be applied to other states and regions to understand and improve their stroke networks of care.

Statement of ethics

This study was conducted in full accordance with all applicable Medical College of Wisconsin Institutional human subjects research

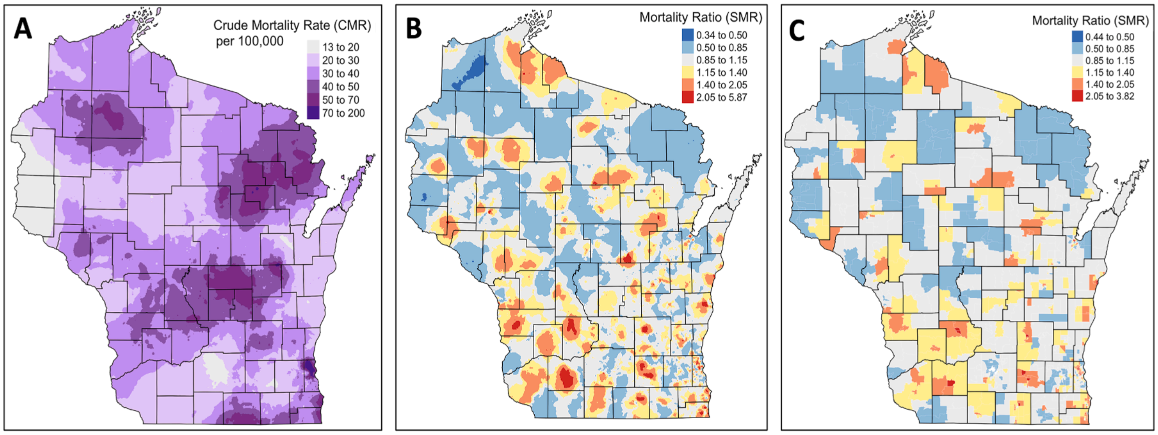

Fig. 2. Continuous crude stroke morality rate in Wisconsin **(A)**; indirect age-sex standardized stroke mortality ratio (SMR) maps in Wisconsin with **(B)** continuous distribution and **(C)** distribution averaged by surface area per census tract. SMR over 1 indicates regional ratios higher than the expected rate.

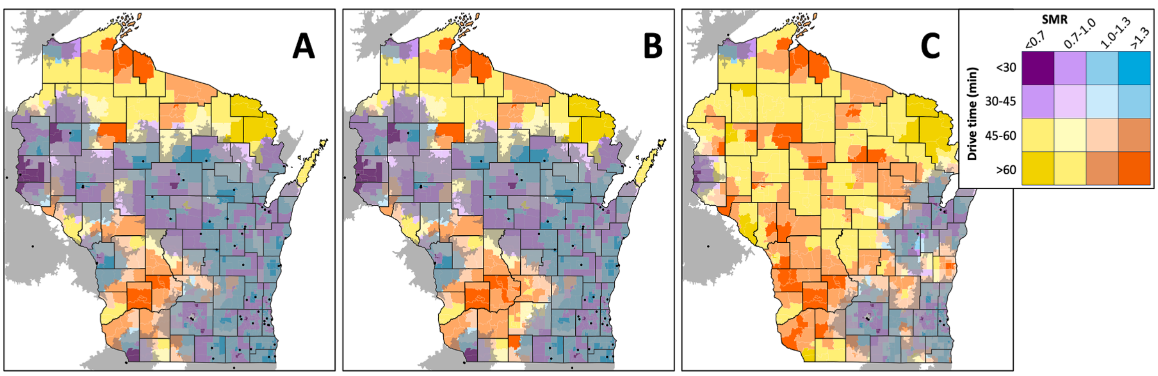

Fig. 3. Heat maps by Wisconsin census tract of categorized indirect age-sex standardized stroke mortality ratios alongside <30, 30-45, 45-60, and >60 minute drive times to the nearest **(A)** certified stroke center, **(B)** basic center, and **(C)** advanced-care-capable center with respective 45-minute drive catchment zone overlay.

requirements and all applicable Federal and state laws and regulations including 45CRF46. This study was reviewed and approved by the Medical College of Wisconsin IRB (PRO00036180), and the investigators performed the study in accordance with this protocol. Collection, recording, and reporting of data was accurate and ensured the privacy, health, and welfare of research subjected during and after the study.

Declaration of Generative AI in Scientific Writing

The authors did not use a generative artificial intelligence (AI) tool or service to assist with preparation or editing of this work. The authors take full responsibility for the content of this publication.

Funding sources

Research reported in this publication (S.H.) was supported by the National Heart, Lung, And Blood Institute of the National Institutes of Health under Award Number T35HL072483. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

National Heart, Lung, And Blood Institute of the National Institutes of Health Award Number T35HL072483.

CRediT authorship contribution statement

Stephen Halada: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Kirsten MM Beyer:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Yuhong Zhou:** Validation, Supervision, Methodology, Formal analysis, Data curation. **Benjamin W Weston:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

Research was conducted in the absence of commercial or financial conflicts. There are no disclosures.

Data availability

The data that support the findings of this study are available on request from the corresponding author, SH. The data are not publicly available due to presence of identifiers (i.e. geocoded addresses, etc).

References

1. Benjamin EJ, Muntner P, Alonso A, Bittencourt MS, Callaway CW, Carson AP, et al. Heart Disease and Stroke Statistics-2019 Update: A Report From the American Heart Association. *Circulation*. 2019;139(10):e56–e528. https://doi.org/10.1161/CIR.0000000000000659. PubMed PMID: 30700139.
2. The Joint Commission. *The Joint Commission Stroke Certification Programs–Program Concept Comparison*. Chicago, IL: The Joint Commission; 2023.
3. McKinney JS, Cheng JQ, Rybinnik I, Kostis JB. Myocardial Infarction Data Acquisition System Study G. Comprehensive stroke centers may be associated with improved survival in hemorrhagic stroke. *J Am Heart Assoc*. 2015;4(5). https://doi.org/10.1161/JAHA.114.001448. Epub 20150506PubMed PMID: 25950185; PubMed Central PMCID: PMCPMC4599399.
4. Kass-Hout T, Lee J, Tataris K, Richards CT, Markul E, Weber J, et al. Prehospital Comprehensive Stroke Center vs Primary Stroke Center Triage in Patients With Suspected Large Vessel Occlusion Stroke. *JAMA Neurol*. 2021;78(10):1220–1227.

https://doi.org/10.1001/jamaneurol.2021.2485. PubMed PMID: 34369969; PubMed Central PMCID: PMCPMC8353578.

5. Adeoye O, Albright KC, Carr BG, Wolff C, Mullen MT, Abruzzo T, et al. Geographic access to acute stroke care in the United States. *Stroke*. 2014;45(10):3019–3024. https://doi.org/10.1161/STROKEAHA.114.006293. Epub 20140826PubMed PMID: 25158773; PubMed Central PMCID: PMCPMC5877807.
6. Lackland DT, Roccella EJ, Deutsch AF, Fornage M, George MG, Howard G, et al. Factors influencing the decline in stroke mortality: a statement from the American Heart Association/American Stroke Association. *Stroke.* 2014;45(1):315–353. https://doi.org/10.1161/01.str.0000437068.30550.cf. Epub 20131205PubMed PMID: 24309587; PubMed Central PMCID: PMCPMC5995123.
7. Zachrison KS, Cash RE, Adeoye O, Boggs KM, Schwamm LH, Mehrotra A, et al. Estimated Population Access to Acute Stroke and Telestroke Centers in the US, 2019. *JAMA Netw Open*. 2022;5(2), e2145824. https://doi.org/10.1001/jamanetworkopen.2021.45824. Epub 20220201PubMed PMID: 35138392; PubMed Central PMCID: PMCPMC8829668.
8. Kamel H, Parikh NS, Chatterjee A, Kim LK, Saver JL, Schwamm LH, et al. Access to Mechanical Thrombectomy for Ischemic Stroke in the United States. *Stroke.* 2021;52 (8):2554–2561. https://doi.org/10.1161/STROKEAHA.120.033485. Epub 20210513PubMed PMID: 33980045; PubMed Central PMCID: PMCPMC8316281.
9. Khan JA, Casper M, Asimos AW, Clarkson L, Enright D, Fehrs LJ, et al. Geographic and sociodemographic disparities in drive times to Joint Commission-certified primary stroke centers in North Carolina, South Carolina, and Georgia. *Prev Chronic Dis*. 2011;8(4):A79. Epub 20110615. PubMed PMID: 21672403; PubMed Central PMCID: PMCPMC3136973.
10. Mullen MT, Wiebe DJ, Bowman A, Wolff CS, Albright KC, Roy J, et al. Disparities in accessibility of certified primary stroke centers. *Stroke*. 2014;45(11):3381–3388. https://doi.org/10.1161/STROKEAHA.114.006021. Epub 20141009PubMed PMID: 25300972; PubMed Central PMCID: PMCPMC4282182.
11. Malhotra K, Gornbein J, Saver JL. Ischemic Strokes Due to Large-Vessel Occlusions Contribute Disproportionately to Stroke-Related Dependence and Death: A Review. *Front Neurol.* 2017;8:651. https://doi.org/10.3389/fneur.2017.00651. Epub 20171130PubMed PMID: 29250029; PubMed Central PMCID: PMCPMC5715197.
12. MacKenzie IER, Moeini-Naghani I, Sigounas D. Trends in Endovascular Mechanical Thrombectomy in Treatment of Acute Ischemic Stroke in the United States. *World Neurosurg*. 2020;138:e839–ee46. https://doi.org/10.1016/j.wneu.2020.03.105. Epub 20200327PubMed PMID: 32229302.
13. Centers for Disease Control and Prevention (CDC) Wide-Ranging Online Data for Epidemiologic Research (WONDER). Underlying Cause of Death 1999-2019 [July 1, 2023].
14. World Health Organization. (2019). International statistical classification of diseases and related health problems (11th ed.).
15. United States Department of Agriculture: Economic Research Service. 2010 Rural-Urban Commuting Area (RUCA) Codes.
16. U.S. Census Bureau. (2015). 2011-2015 American Community Survey 5-year Public Use Microdata Samples.
17. Beyer K, Tiwari C, Rushton G. Five Essential Properties of Disease Maps. *Annals of the Association of American Geographers*. 2012;102(5):1067–1075.
18. Yu CY, Blaine T, Panagos PD, Kansagra AP. Demographic Disparities in Proximity to Certified Stroke Care in the United States. *Stroke.* 2021;52(8):2571–2579. https://doi.org/10.1161/STROKEAHA.121.034493. Epub 20210610PubMed PMID: 34107732; PubMed Central PMCID: PMCPMC8316304.
19. Asimos AW, Enright D, Huston SL, Mettam LH. Drive-time proximity to Joint Commission Primary Stroke Centers among North Carolina residents who died of stroke. *N C Med J*. 2010;71(5):413–420. PubMed PMID: 21473538.
20. Aroor SR, Asif KS, Potter-Vig J, Sharma A, Menon BK, Inoa V, et al. Mechanical Thrombectomy Access for All? Challenges in Increasing Endovascular Treatment for Acute Ischemic Stroke in the United States. *J Stroke*. 2022;24(1):41–48. https://doi.org/10.5853/jos.2021.03909. Epub 20220131PubMed PMID: 35135058; PubMed Central PMCID: PMCPMC8829477.
21. Briggs AC, Black AW, Lucas FL, Siewers AE, Fairfield KM. Association between the food and physical activity environment, obesity, and cardiovascular health across Maine counties. *BMC Public Health*. 2019;19(1):374. https://doi.org/10.1186/s12889-019-6684-6. Epub 20190403PubMed PMID: 30943942; PubMed Central PMCID: PMCPMC6448221.
22. Khan SU, Javed Z, Lone AN, Dani SS, Amin Z, Al-Kindi SG, et al. Social Vulnerability and Premature Cardiovascular Mortality Among US Counties, 2014 to 2018. *Circulation*. 2021;144(16):1272–1279. https://doi.org/10.1161/CIRCULATIONAHA.121.054516. Epub 20211018PubMed PMID: 34662161.
23. Eagles ME, Beall RF, Ben-Israel D, Wong JH, Hill MD, Spackman E. Neighbourhood deprivation, distance to nearest comprehensive stroke centre and access to endovascular thrombectomy for ischemic stroke: a population-based study. *CMAJ Open*. 2023;11(6). https://doi.org/10.9778/cmajo.20230046. E1181-E7. Epub 20231219PubMed PMID: 38114260; PubMed Central PMCID: PMCPMC10743637.
24. Moynihan B, Davis D, Pereira A, Cloud G, Markus HS. Delivering regional thrombolysis via a hub-and-spoke model. *J R Soc Med*. 2010;103(9):363–369. https://doi.org/10.1258/jrsm.2010.090434. PubMed PMID: 20807992; PubMed Central PMCID: PMCPMC2930922.
25. George BP, Pieters TA, Zammit CG, Kelly AG, Sheth KN, Bhalla T. Trends in Interhospital Transfers and Mechanical Thrombectomy for United States Acute Ischemic Stroke Inpatients. *J Stroke Cerebrovasc Dis*. 2019;28(4):980–987. https://doi.org/10.1016/j.jstrokecerebrovasdis.2018.12.018. Epub 20190108PubMed PMID: 30630752.
26. Davis SM, Campbell BCV, Donnan GA. Endovascular Thrombectomy and Stroke Physicians: Equity, Access, and Standards. *Stroke.* 2017;48(8):2042–2044. https://doi.org/10.1161/STROKEAHA.117.018208. Epub 20170713PubMed PMID: 28706115.
27. Masoud H, de Havenon A, Castonguay A, Asif K, Nguyen T, Mehta B, et al. 2022 brief practice update on intravenous thrombolysis before thrombectomy in patients with large vessel occlusion acute ischemic stroke: a statement from society of vascular and interventional Neurology guidelines and practice standards (GAPS) committee. *Stroke: Vascular and Interventional Neurology*. 2022;2(4), e000276.
28. Duvekot MHC, Venema E, Rozeman AD, Moudrous W, Vermeij FH, Biekart M, et al. Comparison of eight prehospital stroke scales to detect intracranial large-vessel occlusion in suspected stroke (PRESTO): a prospective observational study. *Lancet Neurol*. 2021;20(3):213–221. https://doi.org/10.1016/S1474-4422(20)30439-7. Epub 20210107PubMed PMID: 33422191.
29. Shownkeen H, Richards CT, Buffo K, Graham S, Iacob T, Mohajer-Esfahani M, et al. Outcomes of Patients Receiving Thrombolysis in a Mobile Stroke Unit: A 4-Year Retrospective, Observational, Single-Center Study. *Prehosp Emerg Care*. 2023;27(5): 652–658. https://doi.org/10.1080/10903127.2022.2142991. Epub 20221206PubMed PMID: 36357362.
30. Jauch EC, Schwamm LH, Panagos PD, Barbazzeni J, Dickson R, Dunne R, et al. Recommendations for Regional Stroke Destination Plans in Rural, Suburban, and Urban Communities From the Prehospital Stroke System of Care Consensus Conference: A Consensus Statement From the American Academy of Neurology, American Heart Association/American Stroke Association, American Society of Neuroradiology, National Association of EMS Physicians, National Association of State EMS Officials, Society of NeuroInterventional Surgery, and Society of Vascular and Interventional Neurology: Endorsed by the Neurocritical Care Society. *Stroke*. 2021;52(5):e133–ee52. https://doi.org/10.1161/STROKEAHA.120.033228. Epub 20210311PubMed PMID: 33691507.