Healthcare Resource Availability, Quality of Care, and Acute Ischemic Stroke Outcomes

Emily C. O'Brien, PhD; Jingjing Wu, MS; Xin Zhao, MS; Phillip J. Schulte, PhD; Gregg C. Fonarow, MD; Adrian F. Hernandez, MD, MHS; Lee H. Schwamm, MD; Eric D. Peterson, MD, MPH; Deepak L. Bhatt, MD, MPH; Eric E. Smith, MD, MPH

Background—Healthcare resources vary geographically, but associations between hospital-based resources and acute stroke quality and outcomes remain unclear.

Methods and Results—Using Get With The Guidelines-Stroke and Dartmouth Atlas of Health Care data, we examined associations between healthcare resource availability, stroke care, and outcomes. We categorized hospital referral regions with high-, medium-, or low-resource levels based on the 2006 national per-capita availability median of 6 relevant acute stroke care resources. Using multivariable logistic regression, we examined healthcare resource level and in-hospital quality and outcomes. Of 1 480 308 admitted ischemic stroke patients (2006–2013), 28.8% were hospitalized in low-, 44.4% in medium-, and 26.9% in high-resource hospital referral regions. Quality-of-care/timeliness metrics, adjusted length of stay, and in-hospital mortality were similar across all resource levels.

Conclusions—Significant variation exists in regional availability of healthcare resources for acute ischemic stroke treatment, yet among Get With the Guidelines-Stroke hospitals, quality of care and in-hospital outcomes did not differ by regional resource availability. **(*J Am Heart Assoc*. 2017;6:e003813. DOI: 10.1161/JAHA.116.003813.)**

Key Words: healthcare resources • outcomes research • stroke care

Acute stroke is a leading cause of death and disability in the United States.[1] In-hospital management of stroke is complex and costly, and availability of resources for the treatment of stroke varies by geographic region.[2–4] The relationship between resource utilization and acute stroke patient quality of care and outcomes has not been fully established. Access to stroke specialists can support the identification of high-risk patients and selection of those who will benefit from acute interventions that are available at specialized stroke centers.[5] However, results from a number of studies indicate that patients living in regions with more healthcare resources or a greater degree of healthcare spending may not experience higher quality care or better outcomes than those living in regions with fewer resources.[6–9] Whether greater regional healthcare resource availability is associated with better quality of acute stroke care and improved clinical outcomes remains unclear.

We examined the geographic variation in per-capita healthcare resources available for the treatment of acute stroke using publicly available data from the Dartmouth Atlas of Health Care (DAH) and in-hospital data from the Get With The Guidelines-Stroke (GWTG-Stroke) quality improvement initiative. We also estimated the association between availability of resources relevant to the treatment of acute stroke and quality of care in addition to in-hospital outcomes, including complications and mortality.

From the Duke Clinical Research Institute, Durham, NC (E.C.O'., J.W., X.Z., A.F.H., E.D.P.); Department of Health Sciences Research, Mayo Clinic, Rochester, MN (P.J.S.); UCLA Division of Cardiology, Los Angeles, CA (G.C.F.); Stroke Service, Massachusetts General Hospital (L.H.S.) and Brigham and Women's Hospital Heart and Vascular Center (D.L.B.), Harvard Medical School, Boston, MA; University of Calgary, Alberta, Canada (E.E.S.).

Accompanying Tables S1 through S4 are available at http://jaha.ahajournals.org/content/6/2/e003813/DC1/embed/inline-supplementary-material-1.pdf

Correspondence to: Emily C. O'Brien, PhD, Duke Clinical Research Institute, 2400 Pratt Street; Durham, NC 27705. E-mail: emily.obrien@duke.edu

Received April 28, 2016; accepted November 22, 2016.

Methods

Data Sources

We linked data from the American Heart Association's GWTG-Stroke to DAH to ascertain information on healthcare resource distribution. GWTG-Stroke is an ongoing, national quality improvement initiative begun in 2003 to optimize care for hospitalized stroke patients by improving adherence to evidence-based guidelines. Trained personnel enter deidentified demographic, clinical, and event information at participating sites. Details of the GWTG-Stroke program have been previously described.[10,11] The DAH is a publicly available data set that provides numbers of physicians by specialty, hospital-based registered nurses, and inpatient beds per 100 000 residents for individual hospital referral regions (HRRs) in the United States.[7] Healthcare resource data are available from 2003 to 2007. We linked GWTG-Stroke hospitals to referral regions using a crosswalk file from the DAH that links HRR number to zip code for each GWTG-Stroke hospital. There are a total of 306 HRRs defined in the 2006 DAH resource data; the linked GWTG-Stroke hospitals represented 301 of the HRRs. The 5 HRRs not represented in GWTG-Stroke include: (1) Tuscaloosa, Alabama (HRR #9); (2) San Luis Obispo, California (HRR #83); (3) Covington, Kentucky (HRR #203); (4) Hickory, North Carolina (HRR #315); and (5) Elyria, Ohio (HRR #331).

Study Population/Exclusions

Our starting population included 1 525 113 GWTG-Stroke patients aged 18 years and older who were discharged from 1988 sites (January 2006–September 2013) with a final clinical diagnosis indicating ischemic stroke. We excluded patients seen at hospitals with >25% missing medical history data (n=41 632), as well as patients seen at hospitals not in the DAH crosswalk (n=3173). After exclusions, our final analytic population consisted of 1 480 308 patients from 1898 clinical sites.

Exposure Definition

Healthcare resource categories were defined according to the per 100 000 population number of the following: neurologists, radiologists, emergency room physicians, physical medicine and rehabilitation specialists, hospital-based registered nurses, and number of inpatient hospital beds.

We calculated median levels of healthcare resources based on the per-capita distribution of resources for all HRRs in the study sample. We then classified each HRR as high (>50th percentile in at least 5 resource categories), medium (>50th percentile in 3 or 4 categories), or low (>50th percentile in fewer than 3 categories) to produce groups of relatively comparable size and promote stability in effect estimates. The distributions of each healthcare resource are provided in Table S1. In a sensitivity analysis, we examined the association between clinical outcomes and each of the 6 individual resources (Table S2).

Outcome Definition

The primary outcome of interest was performance on quality-of-care indicators and timeliness metrics, estimated at the patient level. Receipt of quality-of-care metrics was estimated for eligible patients only and included venous thromboembolism prophylaxis for patients not ambulating by hospital day 2, antithrombotics by hospital day 2, tissue plasminogen activator (tPA) within 3 hours for patients arriving within 2 hours of symptom onset, anticoagulation for atrial fibrillation, antithrombotics at hospital discharge, lipid-lowering mediation at discharge, dysphagia screening, stroke education, smoking cessation counseling, and assessment for rehabilitation services.[12,13] We also considered performance on a global composite measure, defect-free care, which was defined as the receipt of all performance measures for which the patient was eligible. Timeliness metrics included door-to-brain imaging within 25 minutes, door-to-needle time within 60 minutes for tPA patients, and treatment by 4.5 hours for tPA patients who arrived within 3.5 hours. Secondary outcomes of interest were also estimated at the patient level and included in-hospital complications (pneumonia, deep vein thrombosis/venous thromboembolism, and tPA-related complications), length of inpatient hospital stay, in-hospital mortality, discharged to home, and independent ambulatory status at discharge.

Statistical Analysis

Baseline characteristics, comorbidities, and laboratory data are described overall and by resource availability (high, medium, or low). Categorical variables are presented as counts and proportions; continuous variables are presented as medians with 25th and 75th percentiles. Quality-of-care and timeliness metrics are compared by resource availability using standardized differences. We evaluated the association between healthcare resource availability and length of inpatient hospital stay using multivariable linear regression models. Length of inpatient hospital stay was log-transformed for normality assumptions of the linear regression. The association between resource availability and in-hospital outcomes, including mortality and complications, was assessed using standardized differences (unadjusted) and multivariable logistic regression (adjusted models). All regression models used generalized estimating equations to account for clustering of patients and were adjusted for clinical and hospital characteristics (demographics, comorbidities, medication use, event characteristics, hospital bed size, teaching status, region, and urban/rural location). For linear regression analyses, linearity was assessed for the relationship between continuous adjustment variables and outcomes and transformations applied, as needed. Single imputation was used for missing values, with missing values for continuous variables imputed to the median, and missing values for categorical variables to the most frequent category. Variables with a missing rate of >20% were not considered for adjustment.

Since stroke severity is an important predictor of length of hospital stay and clinical outcomes, a sensitivity analysis further adjusted for stroke severity using the National Institutes of Health Stroke Scale in the subset of patients with non-missing National Institutes of Health Stroke Scale scores (n=898 148; 60.7%). All statistical analyses were performed using SAS software version 9.3 (SAS Institute, Inc., Cary, NC). We considered $P<0.05$ to be statistically significant for all analyses. The GWTG-Stroke study was approved by Duke's institutional review board. All participating hospitals received either approval to enroll without individual patient consent under the common rule or a waiver of exemption from subsequent review by institutional review boards.

Results

Of 1898 hospitals included in the analysis, 29.1% were in low-resource regions, 45.5% in medium-resource regions, and 25.4% in high-resource regions. Of 1 480 308 patients enrolled in GWTG-Stroke from 2006 to 2013, 28.8% were hospitalized at sites in low-resource regions, 44.3% in medium-resource regions, and 26.9% in high-resource regions (Figure). The distribution of patient and event characteristics by regional resource level is provided in Table 1. Age and sex distributions were similar across resource levels, but patients hospitalized in medium-resource regions were more likely to be white than those in low- or high-resource regions. Comorbidity burden was similar across resource levels, with comparable rates of prior stroke/transient ischemic attack,

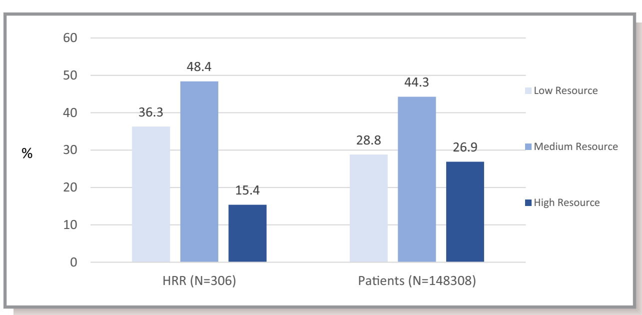

Figure. Proportion of hospital resource regions (HRRs) and Get With The Guidelines-Stroke patients by resource category. This figure displays the proportion of HRRs and patients enrolled in Get With The Guidelines-Stroke Registry by hospital resource level, based on availability per 100 000 residents of neurologists, radiologists, emergency room physicians, physical medicine and rehabilitation specialists, hospital-based registered nurses, and inpatient hospital beds.

diabetes mellitus, coronary artery disease, hypertension, and heart failure across low-, medium-, and high-resource regions. Examination and laboratory data, including body mass index, systolic blood pressure, and cholesterol did not vary substantially by resource region. Patients hospitalized in high-resource regions were more likely to arrive by emergency medical services, but had longer prehospital delays than those hospitalized in lower-resource regions.

Table 2 presents the distribution of evidence-based care metrics by resource region. Receipt of defect-free care was slightly higher for patients hospitalized in high-resource regions. Patients hospitalized in high-resource regions were slightly more likely to receive venous thromboembolism prophylaxis, antithrombotics at discharge, statins at discharge, and smoking cessation counseling than those seen at sites in lower-resource regions; however, standardized differences for these metrics were all less than 10% (the a priori threshold indicating negative correlation between the exposure group and the binary variable[14]). We observed small differences in the proportion of patients meeting timeliness metrics by resource region, with higher proportions of patients receiving tPA within 3 hours and meeting the door-to-needle time of 60 minutes from hospital arrival to tPA administration. On average, patients hospitalized in low-resource regions were less likely to be cared for in a stroke unit (28.1%) than patients in medium- (33.7%) or high- (38.6%) resource regions ($P=0.014$).

The results from a multivariable regression analysis comparing in-hospital outcomes across resource regions are provided in Table 3. After adjusting for demographics, clinical comorbidities, and event characteristics, we found similar rates of venous thromboembolism complications and tPA complications among patients hospitalized at low-, medium-, and high-resource sites (unadjusted hospital-level rates provided in Table S3). Compared with low-resource regions, adjusted in-hospital mortality (odds ratio [OR]; 95% CI) was similar in high-resource regions (OR, 1.00; CI, 0.92, 1.09 [$P=0.92$]) and slightly higher in medium-resource regions (OR, 1.09; CI, 1.02, 1.16 [$P=0.01$]). Examination of two indicators of positive poststroke discharge outcomes—discharge to home and ambulating independently at discharge—did not reveal differences among patients in low-, medium-, or high-resource regions (Table 3). Median length of hospital stay was similar across regions. Results from a sensitivity analysis limited to the population of patients with complete information on stroke severity (National Institutes of Health Stroke Scale) were similar to those results from the overall analysis (data not shown). In a second sensitivity analysis with HRRs reclassified as low (1 category in >50th percentile), medium (2 or 3 categories in >50th percentile), and high (4+ categories in >50th percentile), re-results were similar for all comparisons except for the comparison of high- versus

Table 1. Baseline Patient Characteristics by Regional Resource Level

Variable*	HRR Resource Level†			Standardized Differences	
	Low (n=425 516)	Medium (n=656 348)	High (n=398 444)	Medium vs Low	High vs Low
Demographics					
Median age, y (25th, 75th percentiles)	72.0 (60.0, 82.0)	73.0 (61.0, 83.0)	73.0 (60.0, 82.0)	4.4	2.3
Female sex, No.	51.1	51.6	52.4	1.0	2.7
White race, No.	69.4	73.3	69.4	9.0	0.1
Medical history, No.					
CAD/prior MI	25.8	25.8	27.1	−0.1	2.9
Diabetes mellitus	32.5	31.5	32.4	−2.2	−0.2
Prior stroke/TIA	30.8	30.3	31.1	−1.1	0.6
Smoking	18.6	18.3	19.3	−1.0	1.6
AF	17.3	18.8	18.4	4.0	2.9
HF	7.0	7.4	8.1	1.5	4.0
Hypertension	75.1	75.2	76.4	0.2	3.1
Laboratory and examination data					
BMI, kg/m^2, median (25th, 75th percentiles)	26.8 (23.4, 31.1)	26.9 (23.4, 31.2)	27.1 (23.5, 31.4)	0.6	3.2
SBP, mm Hg, median (25th, 75th percentiles)	154 (135, 176)	154 (136, 176)	154 (136, 176)	0.4	1.6
Total cholesterol, mg/dL, median (IQR)	167 (139–200)	167 (138–199)	167 (139–200)	−1.2	−0.1
LDL-C, mg/dL, median (25th, 75th percentiles)	98 (75, 126)	98 (74, 125)	98 (74, 126)	−1.7	−1.3
Event characteristics					
EMS arrival	48.3	47.6	50.2	−1.4	3.8
Median prehospital delay, min	699 (141, 2118)	694 (145, 2110)	717 (162, 2149)	0.0	0.0
Ambulating by day 2	44.2	44.2	41.7	0.1	−5.1
NIHSS score, median	4.0 (2.0, 11.0)	4.0 (2.0, 10.0)	4.0 (2.0, 10.0)	−2.8	−3.6

AF indicates atrial fibrillation; AMI, acute myocardial infarction; BMI, body mass index; CAD, coronary artery disease; EMS, emergency medical services; HF, heart failure; HRR, hospital referral region; IQR, interquartile range; LDL-C, low-density lipoprotein cholesterol; MI, myocardial infarction; NIHSS, National Institutes of Health Stroke Scale; SBP, systolic blood pressure; TIA, transient ischemic attack.

*Chi-square tests used for categorical variables and Kruskal–Wallis tests for continuous variables. All *P* values for comparison were <0.0001. Values are percentages unless otherwise indicated.

†Based on availability per 100 000 residents of neurologists, radiologists, emergency room physicians, physical medicine and rehabilitation specialists, hospital-based registered nurses, and inpatient hospital beds.

low-resource availability and in-hospital mortality, which was not significant in the original analysis but became significant in the reclassified analysis (Table S4).

In a sensitivity analysis examining outcomes by each of the 6 individual healthcare resources, we found that greater availability of neurologists and physical medicine and rehabilitation specialists (per 100 000 residents) and fewer inpatient beds (per 100 000 residents) were associated with higher adjusted rates of defect-free care (Table S2). Greater availability of neurologists, physical medicine and rehabilitation specialists, and inpatient hospital beds were associated with greater length of hospital stay. No associations were observed for individual resource availability and in-hospital mortality, ambulatory status at discharge, tPA-related complications, or venous thromboembolism.

Discussion

In this study, we examined the availability of 6 healthcare resources relevant to acute ischemic stroke and length of stay, rates of complications, and in-hospital mortality. We had several major findings. First, the majority of patients with acute ischemic stroke enrolled in GWTG-Stroke were hospitalized in medium-resource regions, followed by low-resource and-high resource regions. Second, comorbidity burden was similar across patients admitted for acute ischemic stroke to hospitals in high-, medium-, and low-resource HRRs. Third, hospitals in high- and medium-resource HRRs were more likely to deliver defect-free care than those in low-resource HRRs, but this difference was small. Finally, among hospitals participating in GWTG-Stroke, adjusted estimates of

Table 2. Healthcare Resource Availability and Acute Stroke Care

	HRR Resource Level, %*			Standardized Differences, %†	
	Low (n=425 516)	Medium (n=656 348)	High (n=398 444)	Medium vs Low	High vs Low
Defect-free care‡	86.4	87.3	87.4	2.9	3.0
Anticoagulation for AF patients	93.0	93.5	93.7	1.8	2.8
Antithrombotics at discharge	97.2	97.5	97.6	2.3	2.6
Dysphagia screening	77.5	78.7	77.5	2.9	0.0
VTE prophylaxis	96.6	97.2	97.1	3.4	2.5
Statins at discharge	89.9	90.4	90.8	1.9	3.1
Assessed for/received rehabilitation	92.0	92.5	92.4	1.8	1.3
Antithrombotics by day 2	96.1	96.4	96.3	2.0	1.1
Smoking cessation counseling	95.5	96.1	95.5	2.9	0.1
Stroke education	72.1	73.3	71.0	2.7	−2.4
Timeliness metrics					
tPA Rx (arrive ≤3.5 h, treat ≤4.5 h)	39.3	40.5	37.9	2.5	−2.9
tPA Rx (arrive ≤2 h, treat ≤3 h)	74.1	75.2	74.9	2.5	1.9
Door-to-imaging ≤25 min	24.2	24.5	23.8	0.6	−0.9
Door-to-needle ≤60 min (tPA only)	35.5	36.0	34.2	1.2	−2.6
Cared for in stroke unit	64.5	66.9	65.7	5.1	2.5

AF indicates atrial fibrillation; HRR, hospital referral region; Rx, prescription; tPA, tissue plasminogen activator; VTE, venous thromboembolism.
*Based on availability per 100 000 residents of neurologists, radiologists, emergency room physicians, physical medicine and rehabilitation specialists, hospital-based registered nurses, and inpatient hospital beds.
†A standardized difference greater than 10% is typically considered meaningful.[14]
‡Receipt of all stroke performance metrics for which the patient was eligible. Eligibility was defined separately for individual metrics.

in-hospital outcomes did not differ by availability of the 6 selected resource metrics.

Facilitating access to specialized care has received increasing focus as a mechanism for reducing stroke morbidity and mortality, as evidenced by numerous recent telemedicine and related initiatives aimed at increasing access to stroke specialists in under-resourced and underserved populations.[15,16] These efforts are founded on a growing body of evidence suggesting that involvement of nursing and physician specialists in acute stroke care may have a direct impact on health outcomes.[17] In a population of patients treated at 42 academic medical centers in the University Health Systems Consortium, in-hospital mortality rates were substantially lower in academic centers with a vascular neurologist, as well as those who limited tPA administration to neurologists, compared with other academic centers.[18] In a comparison of in-hospital outcomes in patients in the Veterans Affairs Stroke Study treated by either a neurologist or a non-neurologist, Goldstein and colleagues[19] reported that patients treated by a neurologist were 37% less likely to be dead or dependent at discharge,

Table 3. Multivariable Adjusted* Odds Ratios (95% CIs) Comparing Patient Outcomes by Healthcare Resource Availability

Outcome	Low	Medium	*P* Value	High	*P* Value
In-hospital complications					
Venous thromboembolism	Ref	1.13 (0.78–1.62)	0.52	1.04 (0.74–1.45)	0.84
tPA-related complications†	Ref	1.08 (0.83–1.42)	0.56	0.82 (0.58–1.15)	0.24
In-hospital mortality	Ref	1.09 (1.02–1.16)	0.01	1.00 (0.92–1.09)	0.92
Discharged to home	Ref	0.99 (0.95–1.03)	0.70	0.97 (0.92–1.02)	0.29
Ambulating independently at discharge	Ref	1.01 (0.94–1.08)	0.79	0.96 (0.89–1.05)	0.38
Length of inpatient stay, d	Ref	1.00 (0.98–1.02)	0.89	1.001 (0.99–1.03)	0.50

*Adjusted for patient and hospital characteristics.
†Tissue plasminogen activator (tPA) patients only.

regardless of event severity or differences in comorbidity burden. One likely mechanism for these patterns is improved adherence to evidence-based metrics in centers with higher resource availability. In one analysis of 4897 patients in the Paul Coverdell National Acute Stroke Registry, Reeves and colleagues[20] reported that involvement of a neurologist in stroke care was associated with a 4.9% increase in the proportion of filled care opportunities. Consistent with this prior work, we found that increasing availability of neurologists was associated with higher adjusted rates of defect-free care. In another analysis of Medicare claims data, patients treated by neurologists had significantly lower adjusted 90-day mortality rates compared with those who were not. These differences may have been due to increased adherence to evidence-based guidelines, such as prescription of warfarin, and a higher proportion of patients who were discharged to inpatient rehabilitation facilities.[21]

Despite the evidence supporting increased access to specialists for delivery of high-quality stroke care, less is known about the influence of healthcare resource regional variation on quality and outcomes. In a landmark study assessing quality and cost differences among Medicare beneficiaries, Baicker and colleagues[6] reported that areas with a higher number of specialists per capita had higher healthcare costs and were less likely to deliver high-quality care; availability of nurses was not associated with variation in quality or cost. Additionally, increasing the number of general practitioners by 1 per 10 000 per state, while decreasing the number of specialists, was associated with a reduction in spending and a 10-place rise in the state's quality rank. However, the authors considered 24 quality measures for the treatment of both chronic and acute conditions, and prior work suggests the importance of specialist availability, particularly for acute conditions.[22]

We extend this prior work by considering specialist availability, as well as a broader set of healthcare resources and additional relevant clinical outcomes, such as in-hospital complications, in a large national database of acute stroke. We did not find significant associations with quality or in-hospital outcomes across regions categorized as having low-, medium-, or high-resource availability. One possible explanation for our findings is the nature of the analytic population. GWTG-Stroke is a large national quality improvement initiative that has been shown to be representative of the larger stroke population in the United States.[23] However, GWTG-Stroke is a network of hospitals that facilitates sharing of best practices and quality improvement strategies, and evidence suggests that program participation is linked to sustained improvements in delivery of evidence-based quality metrics independent of hospital volume, bed size, or teaching status.[11] Absolute adherence to quality metrics were high among most participating hospitals. Therefore, it is possible that GWTG-Stroke hospitals represent a select sample of centers that are particularly focused on improving quality of care and outcomes, which may minimize quality differences attributable to variation in resource availability. Another possible explanation for these findings is the choice of resources for assessment. We selected 6 resources relevant to the care of acute stroke patients that were collected as part of the DAH project. Nevertheless, there are likely other healthcare resources relevant to acute stroke care, and it is possible that differences in the number of clinicians and in-hospital beds may be too small to fully reflect important differences in resource availability.

Study Limitations

Several limitations to our analysis are worth noting. First, a number of factors likely influence regional availability of healthcare resources, including variation in stroke incidence, complexity of patients, and event severity. While the detailed clinical information captured in GWTG-Stroke supports adjustment for differences in case mix, it is possible that there were unmeasured characteristics of the patient population that influenced our findings. Second, we did not have specific information on regional availability of stroke unit staffing and resources. For example, we did not have information on the use of a telemedicine program at each hospital, and access to such programs may reduce the influence of geographic variation in stroke resources on acute stroke outcomes. Third, our clinical end point analysis focused on in-hospital outcomes including mortality and complications, yet delivery of high-quality care/evidence-based medications at discharge, stroke education, and rehabilitation services may result in longer-term benefits that are not apparent for several months after hospital discharge. Fourth, residual measured and unmeasured confounding may have influenced these findings. Additionally, we defined HRRs as low, medium, and high based on DAH data, which is only publicly available for 2006; therefore, we were unable to account for changing resource availability over the study period (2006–2013). Fifth, effect estimates for many analyses are small in magnitude and, while statistically significant, may not represent clinically significant differences. Finally, we focused on the availability of hospital-based resources for acute stroke. Availability of primary care and other providers in the outpatient setting may influence prestroke and poststroke medication adherence and access to secondary prevention strategies.

Conclusions

Significant variation exists in regional availability of healthcare resources for the treatment of acute ischemic stroke.

However, among 1898 hospitals participating in GWTG-Stroke, quality of care and in-hospital outcomes for acute ischemic stroke did not differ significantly by selected metrics of regional resource availability. Further exploration of other relevant markers of resource availability and outcomes is warranted.

Acknowledgments

We thank Erin Hanley, MS, Duke Clinical Research Institute, for editorial assistance and article preparation. She did not receive compensation for her assistance apart from her employment at the institution where the study was conducted. The authors would like to thank the staff and participants of the Get With The Guidelines-Stroke Registry for their important contributions to this work.

Sources of Funding

The American Heart Association funded Get With The Guidelines-Stroke. The program has been supported in part by unrestricted educational grants to the American Heart Association by Pfizer, Inc., New York, NY, and the Merck-Schering Plough Partnership (North Wales, PA). This project was funded by the American Heart Association's Young Investigator Database Research Seed Grant.

Disclosures

Dr Fonarow reports serving as a member of the Get With The Guidelines (GWTG) steering committee; receiving significant research support from the National Institutes of Health; and being an employee of the University of California, which holds a patent on retriever devices for stroke. Dr Hernandez reports receiving a research grant from Amgen, Bristol Myers Squibb, GlaxoSmithKline, Janssen, Novartis, and Portola Pharmaceuticals; and receiving honoraria from Amgen, GlaxoSmithKline, Janssen, and Novartis. Dr Schwamm reports being the principal investigator of an investigator-initiated study of extended-window intravenous thrombolysis funded by the National Institute of Neurological Disorders and Stroke (clinicaltrials.gov/show/NCT01282242) for which Genentech provides alteplase free of charge to Massachusetts General Hospital as well as supplemental per-patient payments to participating sites; serving as chair of the American Heart Association/American Stroke Association GWTG stroke clinical work group; serving as a stroke systems consultant to the Massachusetts Department of Public Health; and serving as a scientific consultant regarding trial design and conduct to Lundbeck (international steering committee, DIAS-3 and -4) and Penumbra (data and safety monitoring committee, Separator 3D trial). Dr Peterson reports receiving research grants from Lilly, Johnson & Johnson, Bristol-Myers Squibb, Sanofi-Aventis, and Merck-Schering Plough partnership; and serving as principal investigator of the data analytic center for the American Heart Association/American Stroke Association GWTG. Dr Bhatt discloses the following relationships—Advisory Board: Cardax, Elsevier Practice Update Cardiology, Medscape Cardiology, Regado Biosciences; Board of Directors: Boston VA Research Institute, Society of Cardiovascular Patient Care; Chair: American Heart Association Quality Oversight Committee; Data Monitoring Committees: Duke Clinical Research Institute, Harvard Clinical Research Institute, Mayo Clinic, Population Health Research Institute; Honoraria: American College of Cardiology (Senior Associate Editor, Clinical Trials and News, ACC.org), Belvoir Publications (Editor in Chief, Harvard Heart Letter), Duke Clinical Research Institute (clinical trial steering committees), Harvard Clinical Research Institute (clinical trial steering committee), HMP Communications (Editor in Chief, Journal of Invasive Cardiology), *Journal of the American College of Cardiology* (Guest Editor; Associate Editor), Population Health Research Institute (clinical trial steering committee), Slack Publications (Chief Medical Editor, Cardiology Today's Intervention), Society of Cardiovascular Patient Care (Secretary/Treasurer), WebMD (CME steering committees); Other: Clinical Cardiology (Deputy Editor), NCDR-ACTION Registry Steering Committee (Chair), VA CART Research and Publications Committee (Chair); Research Funding: Amarin, Amgen, AstraZeneca, Bristol-Myers Squibb, Eisai, Ethicon, Forest Laboratories, Ischemix, Medtronic, Pfizer, Roche, Sanofi Aventis, The Medicines Company; Royalties: Elsevier (Editor, Cardiovascular Intervention: A Companion to Braunwald's Heart Disease); Site Co-Investigator: Biotronik, Boston Scientific, St. Jude Medical; Trustee: American College of Cardiology; Unfunded Research: FlowCo, PLx Pharma, Takeda. The remaining authors have no disclosures to report.

References

1. Mozaffarian D, Benjamin EJ, Go AS, Arnett DK, Blaha MJ, Cushman M, Das SR, de Ferranti S, Despres JP, Fullerton HJ, Howard VJ, Huffman MD, Isasi CR, Jimenez MC, Judd SE, Kissela BM, Lichtman JH, Lisabeth LD, Liu S, Mackey RH, Magid DJ, McGuire DK, Mohler ER III, Moy CS, Muntner P, Mussolino ME, Nasir K, Neumar RW, Nichol G, Palaniappan L, Pandey DK, Reeves MJ, Rodriguez CJ, Rosamond W, Sorlie PD, Stein J, Towfighi A, Turan TN, Virani SS, Woo D, Yeh RW, Turner MB. Heart disease and stroke statistics—2016 update: a report from the American Heart Association. *Circulation*. 2016;133:e38–e360.
2. Baicker K, Chandra A, Skinner JS, Wennberg JE. Who you are and where you live: how race and geography affect the treatment of Medicare beneficiaries. *Health Aff (Millwood)*. 2004;Suppl Variation:VAR33–VAR44.
3. Radley DC, Schoen C. Geographic variation in access to care–the relationship with quality. *N Engl J Med*. 2012;367:3–6.
4. Gois CF, Dantas RA. Stressors in care at a thoracic surgery postoperative unit: nursing evaluation [Article in Portuguese]. *Rev Lat Am Enfermagem*. 2004;12:22–27.
5. Schwamm LH, Holloway RG, Amarenco P, Audebert HJ, Bakas T, Chumbler NR, Handschu R, Jauch EC, Knight WA IV, Levine SR, Mayberg M, Meyer BC, Meyers PM, Skalabrin E, Wechsler LR; American Heart Association Stroke Council; Interdisciplinary Council on Peripheral Vascular Disease. A review of the evidence for the use of telemedicine within stroke systems of care: a scientific statement from the American Heart Association/American Stroke Association. *Stroke*. 2009;40:2616–2634.

6. Baicker K, Chandra A. Medicare spending, the physician workforce, and beneficiaries' quality of care. *Health Aff (Millwood)*. 2004;Suppl Web Exclusives:W4-184-197.
7. Goodman DC, Fisher ES, Bronner KK. Hospital and physician capacity update: a brief report from the Dartmouth Atlas of Health Care. The Dartmouth Atlas of Health Care eb site. Published March 30, 2009. Available at: http://www.dartmouthatlas.org/downloads/reports/Capacity_Report_2009.pdf. Accessed September 17, 2015.
8. Yasaitis L, Fisher ES, Skinner JS, Chandra A. Hospital quality and intensity of spending: is there an association? *Health Aff (Millwood)*. 2009;28:w566–w572.
9. Fisher ES, Wennberg DE, Stukel TA, Gottlieb DJ, Lucas FL, Pinder EL. The implications of regional variations in Medicare spending. Part 1: the content, quality, and accessibility of care. *Ann Intern Med*. 2003;138:273–287.
10. LaBresh KA, Reeves MJ, Frankel MR, Albright D, Schwamm LH. Hospital treatment of patients with ischemic stroke or transient ischemic attack using the "Get With The Guidelines" program. *Arch Intern Med*. 2008;168:411–417.
11. Schwamm LH, Fonarow GC, Reeves MJ, Pan W, Frankel MR, Smith EE, Ellrodt G, Cannon CP, Liang L, Peterson E, Labresh KA. Get With the Guidelines-Stroke is associated with sustained improvement in care for patients hospitalized with acute stroke or transient ischemic attack. *Circulation*. 2009;119:107–115.
12. Fonarow GC, Reeves MJ, Smith EE, Saver JL, Zhao X, Olson DW, Hernandez AF, Peterson ED, Schwamm LH; GWTG-Stroke Steering Committee and Investigators. Characteristics, performance measures, and in-hospital outcomes of the first one million stroke and transient ischemic attack admissions in get with the guidelines-stroke. *Circ Cardiovasc Qual Outcomes*. 2010;3:291–302.
13. Reeves MJ, Parker C, Fonarow GC, Smith EE, Schwamm LH. Development of stroke performance measures: definitions, methods, and current measures. *Stroke*. 2010;41:1573–1578.
14. Austin PC. Using the standardized difference to compare the prevalence of a binary variable between two groups in observational research. *Commun Stat Simul Comput*. 2009;38:1228–1234.
15. Schwamm LH, Pancioli A, Acker JE III, Goldstein LB, Zorowitz RD, Shephard TJ, Moyer P, Gorman M, Johnston SC, Duncan PW, Gorelick P, Frank J, Stranne SK, Smith R, Federspiel W, Horton KB, Magnis E, Adams RJ; American Stroke Association's Task Force on the Development of Stroke Systems. Recommendations for the establishment of stroke systems of care: recommendations from the American Stroke Association's Task Force on the Development of Stroke Systems. *Stroke*. 2005;36:690–703.
16. Saposnik G, Fang J, O'Donnell M, Hachinski V, Kapral MK, Hill MD; Investigators of the Registry of the Canadian Stroke Network (RCSN) for the Stroke Outcome Research Canada (SORCan) Working Group. Escalating levels of access to in-hospital care and stroke mortality. *Stroke*. 2008;39:2522–2530.
17. Bray BD, Ayis S, Campbell J, Cloud GC, James M, Hoffman A, Tyrrell PJ, Wolfe CD, Rudd AG. Associations between stroke mortality and weekend working by stroke specialist physicians and registered nurses: prospective multicentre cohort study. *PLoS Med*. 2014;11:e1001705.
18. Gillum LA, Johnston SC. Characteristics of academic medical centers and ischemic stroke outcomes. *Stroke*. 2001;32:2137–2142.
19. Goldstein LB, Matchar DB, Hoff-Lindquist J, Samsa GP, Horner RD. VA Stroke Study: neurologist care is associated with increased testing but improved outcomes. *Neurology*. 2003;61:792–796.
20. Reeves MJ, Gargano J, Maier KS, Broderick JP, Frankel M, LaBresh KA, Moomaw CJ, Schwamm L. Patient-level and hospital-level determinants of the quality of acute stroke care: a multilevel modeling approach. *Stroke*. 2010;41:2924–2931.
21. Mitchell JB, Ballard DJ, Whisnant JP, Ammering CJ, Samsa GP, Matchar DB. What role do neurologists play in determining the costs and outcomes of stroke patients? *Stroke*. 1996;27:1937–1943.
22. Jollis JG, DeLong ER, Peterson ED, Muhlbaier LH, Fortin DF, Califf RM, Mark DB. Outcome of acute myocardial infarction according to the specialty of the admitting physician. *N Engl J Med*. 1996;335:1880–1887.
23. Reeves MJ, Fonarow GC, Smith EE, Pan W, Olson D, Hernandez AF, Peterson ED, Schwamm LH. Representativeness of the Get With The Guidelines-Stroke Registry: comparison of patient and hospital characteristics among Medicare beneficiaries hospitalized with ischemic stroke. *Stroke*. 2012;43:44–49.

SUPPLEMENTAL MATERIAL

Table S1. Distribution of 6 Healthcare Resources Per 100,000 population across 306 HRRs in the DAH.

Variables	*N*	*Mean*	*STD*	*Median*	*Q1*	*Q3*	*Min*	*Max*
Neurologists	306	3.313	1.151	3.154	2.524	3.880	0.875	9.782
Radiologists	306	8.632	1.889	8.532	7.374	9.630	2.834	14.497
ER physicians	306	9.009	2.919	8.862	6.888	10.623	1.529	20.238
PM&R specialists	306	2.064	0.871	1.926	1.486	2.566	0.307	5.490
Hospital-based RNs	306	3.730	0.665	3.725	3.288	4.215	2.112	5.732
Inpatient hospital beds	306	2.515	0.618	2.407	2.055	2.909	1.445	4.707

HRR indicates hospital referral region; DAH: Dartmouth Atlas of Health Care; ER: emergency room; PM&R: physical medicine and rehabilitation specialist; RN: registered nurse

Table S2. Clinical Outcomes in GWTG-Stroke*

Length of stay	**Univariate RR**	**p-value**	**Adjusted RR**	**p-value**
Neurologists	1.03 (1.03, 1.04)	<0.0001	1.01 (1.00, 1.02)	0.0068
Radiologists	1.01 (1.01, 1.02)	<0.0001	1.00 (1.00, 1.00)	0.9539
ER physicians	0.98 (0.98, 0.99)	<0.0001	0.99 (0.99, 0.99)	<0.0001
PM&R specialists	1.05 (1.04, 1.06)	<0.0001	1.04 (1.03, 1.05)	<0.0001
Hospital-based RNs	1.04 (1.03, 1.06)	<0.0001	1.01 (1.00, 1.02)	0.1505
Inpatient hospital beds	1.11 (1.09, 1.13)	<0.0001	1.06 (1.05, 1.08)	<0.0001
Defect-free care	**Univariate OR**	**p-value**	**Adjusted OR**	**p-value**
Neurologists	1.09 (1.06, 1.12)	<0.0001	1.04 (1.01, 1.06)	0.0065
Radiologists	1.04 (1.03, 1.06)	<0.0001	1.02 (1.00, 1.03)	0.0561
ER physicians	1.03 (1.01, 1.05)	0.0003	1.01 (1.00, 1.03)	0.0778
PM&R specialists	1.11 (1.07, 1.15)	<0.0001	1.05 (1.02, 1.09)	0.0047
Hospital-based RNs	0.91 (0.86, 0.96)	0.0012	1.02 (0.96, 1.08)	0.5401
Inpatient hospital beds	0.77 (0.72, 0.83)	<0.0001	0.91 (0.85, 0.97)	0.0052
In-hospital mortality	**Univariate OR**	**p-value**	**Adjusted OR**	**p-value**
Neurologists	1.02 (1.00, 1.04)	0.0116	1.01 (0.99, 1.04)	0.2581
Radiologists	1.02 (1.01, 1.03)	0.0031	1.00 (0.99, 1.02)	0.7609
ER physicians	1.00 (0.99, 1.01)	0.7689	0.99 (0.98, 1.01)	0.2850
PM&R specialists	1.06 (1.03, 1.08)	<0.0001	1.01 (0.98, 1.05)	0.4469
Hospital-based RNs	0.96 (0.93, 1.00)	0.0470	1.03 (0.97, 1.08)	0.3059
Inpatient hospital beds	0.98 (0.94, 1.03)	0.4287	1.06 (1.00, 1.13)	0.0538
Discharged to home	**Univariate OR**	**p-value**	**Adjusted OR**	**p-value**
Neurologists	0.96 (0.95, 0.97)	<0.0001	1.00 (0.99, 1.01)	0.889
Radiologists	0.97 (0.96, 0.98)	<0.0001	1.00 (0.99, 1.01)	0.910
ER physicians	0.99 (0.99, 1.00)	0.043	1.00 (1.00, 1.01)	0.416
PM&R specialists	0.94 (0.93, 0.96)	<0.0001	0.99 (0.97, 1.01)	0.366
Hospital-based RNs	0.97 (0.95, 1.00)	0.040	0.97 (0.94, 1.00)	0.041
Inpatient hospital beds	0.98 (0.95, 1.01)	0.203	0.91 (0.87, 0.94)	<0.0001
Ambulating independently at discharge	**Univariate OR**	**p-value**	**Adjusted OR**	**p-value**
Neurologists	0.98 (0.96, 1.00)	0.016	0.99 (0.97, 1.01)	0.306
Radiologists	0.98 (0.97, 0.99)	0.001	0.99 (0.98, 1.01)	0.245
ER physicians	1.00 (0.99, 1.01)	0.609	1.00 (0.98, 1.01)	0.563
PM&R specialists	0.99 (0.97, 1.02)	0.687	1.01 (0.97, 1.04)	0.669
Hospital-based RNs	0.97 (0.93, 1.02)	0.200	0.95 (0.90, 1.01)	0.124

Inpatient hospital beds	0.97 (0.92, 1.03)	0.352	0.95 (0.88, 1.03)	0.199
t-PA-related complications	**Univariate OR**	**p-value**	**Adjusted OR**	**p-value**
Neurologists	0.95 (0.90, 1.00)	0.061	0.98 (0.90, 1.05)	0.520
Radiologists	0.96 (0.92, 1.00)	0.043	0.96 (0.92, 1.00)	0.054
ER physicians	0.95 (0.92, 0.99)	0.017	0.97 (0.93, 1.00)	0.067
PM&R specialists	0.83 (0.71, 0.96)	0.014	0.84 (0.71, 1.00)	0.052
Hospital-based RNs	0.96 (0.85, 1.08)	0.472	0.90 (0.76, 1.07)	0.223
Inpatient hospital beds	1.09 (0.83, 1.43)	0.523	0.99 (0.74, 1.32)	0.944
Venous thromboembolism	**Univariate OR**	**p-value**	**Adjusted OR**	**p-value**
Neurologists	1.07 (0.95, 1.21)	0.289	1.08 (0.96, 1.20)	0.197
Radiologists	1.06 (1.00, 1.12)	0.063	1.03 (0.98, 1.09)	0.260
ER physicians	1.00 (0.96, 1.04)	0.958	1.01 (0.95, 1.07)	0.754
PM&R specialists	0.98 (0.74, 1.30)	0.896	0.91 (0.69, 1.19)	0.476
Hospital-based RNs	0.97 (0.82, 1.15)	0.754	1.00 (0.76, 1.32)	0.990
Inpatient hospital beds	0.73 (0.42, 1.29)	0.282	0.77 (0.44, 1.35)	0.362

*ORs are for every 1 unit increase per 1,000 residents for inpatient hospital beds and hospital-based RNs, and for every 1 unit increase per 100,000 residents for neurologists, ER physicians, PM&R specialists, and radiologists

ER indicates emergency room; GWTG-Stroke, Get With The Guidelines-Stroke; OR, odds ratio; PM&R, physical medicine and rehabilitation specialist; RN, registered nurse; RR, risk ratio; t-PA, tissue plasminogen activator

Table S3. Hospital-level Outcomes in GWTG-Stroke.

Outcomes	Mean	STD	Median	Q1	Q3
In-Hospital Complications: Venous thromboembolism	1.90	3.06	1.42	0.97	2.08
In-Hospital Complications: t-PA related complications	15.48	11.47	12.84	9.71	17.45
In-hospital mortality	5.00	1.78	4.92	3.92	6.12
Discharged to home	47.52	5.87	47.21	43.82	50.65
Ambulatory independently at discharge	51.08	8.05	50.85	46.18	55.41
Length of Hospital stay in days >=4	53.62	9.55	54.63	48.17	59.38

Table S4. Multivariable Adjusted* Odds Ratios (95% CI) Comparing Patient Outcomes by Healthcare Resource Availability (reclassified).

Outcome	Low (N=46)	Medium (N=150)	p-value	High (N=110)	p-value
In-hospital complications					
Venous thromboembolism	ref	0.96 (0.66 , 1.40)	0.831	0.87 (0.56 , 1.35)	0.540
t-PA related complications†	ref	1.09 (0.79 , 1.51)	0.587	0.91 (0.58 , 1.42)	0.669
In-hospital mortality	ref	1.18 (1.08 , 1.29)	<0.001	1.16 (1.05 , 1.27)	0.002
Discharged to home	ref	1.00 (0.95 , 1.06)	0.943	0.99 (0.93 , 1.04)	0.649
Ambulating independently at discharge	ref	0.99 (0.90 , 1.08)	0.805	0.96 (0.87 , 1.05)	0.357
Length of inpatient stay (days)	ref	1.00 (0.98 , 1.02)	0.949	1.01 (0.98 , 1.04)	0.480

*Adjusted for patient and hospital characteristics

†t-PA patients only

t-PA indicates tissue plasminogen activator.