JAMA Internal Medicine | Original Investigation

Primary Stroke Center Hospitalization for Elderly Patients With Stroke
Implications for Case Fatality and Travel Times

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IMPORTANCE Physicians often must decide whether to treat patients with acute stroke locally or refer them to a more distant Primary Stroke Center (PSC). There is little evidence on how much the increased risk of prolonged travel time offsets benefits of a specialized PSC care.

OBJECTIVES To examine the association of case fatality with receiving care in PSCs vs other hospitals for patients with stroke and to identify whether prolonged travel time offsets the effect of PSCs.

DESIGN, SETTING, AND PARTICIPANTS Retrospective cohort study of Medicare beneficiaries with stroke admitted to a hospital between January 1, 2010, and December 31, 2013. Drive times were calculated based on zip code centroids and street-level road network data. We used an instrumental variable analysis based on the differential travel time to PSCs to control for unmeasured confounding. The setting was a 100% sample of Medicare fee-for-service claims.

EXPOSURES Admission to a PSC.

MAIN OUTCOMES AND MEASURES Seven-day and 30-day postadmission case-fatality rates.

RESULTS Among 865 184 elderly patients with stroke (mean age, 78.9 years; 55.5% female), 53.9% were treated in PSCs. We found that admission to PSCs was associated with 1.8% (95% CI, −2.1% to −1.4%) lower 7-day and 1.8% (95% CI, −2.3% to −1.4%) lower 30-day case fatality. Fifty-six patients with stroke needed to be treated in PSCs to save one life at 30 days. Receiving treatment in PSCs was associated with a 30-day survival benefit for patients traveling less than 90 minutes, but traveling at least 90 minutes offset any benefit of PSC care.

CONCLUSIONS AND RELEVANCE Hospitalization of patients with stroke in PSCs was associated with decreased 7-day and 30-day case fatality compared with noncertified hospitals. Traveling at least 90 minutes to receive care offset the 30-day survival benefit of PSC admission.

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JAMA Intern Med. 2016;176(9):1361-1368. doi:10.1001/jamainternmed.2016.3919
Published online July 25, 2016.

Stroke is one of the leading causes of death and long-term disability in the United States.[1,2] In an effort to maximize positive outcomes, referral centers have been established to ensure adherence to guidelines and efficient delivery of disease-specific care.[3] The backbone of this effort is the certification of Primary Stroke Centers (PSCs) by The Joint Commission (TJC). Several groups have demonstrated a small case-fatality benefit from stroke center hospitalization for patients with hemorrhagic and ischemic stroke.[4-6] However, previous investigations were either based on regional centers of excellence (not certified by a national agency)[6] or did not adjust for unmeasured confounders.

Positive outcomes for patients with stroke depend on the timely administration of thrombolytics, evaluation for endovascular treatment, neurosurgical consultation in cases of hemorrhage, and targeted neurocritical care. The implementation of regionalization incentives (directing all patients with stroke to PSCs), similar to other areas of medicine,[7-10] can have a significant effect on travel times and outcomes, which is of particular importance when considering the well-recognized access disparities for PSCs across states.[11-14] Therefore, the potential benefit of an admission to a PSC needs to be weighed against the effect of longer travel times. To our knowledge, previous literature[15] has not addressed this question, leaving a critical knowledge gap for the emergency systems involved in the care of patients with stroke.

We used a national cohort of Medicare beneficiaries to identify how much the increased risk of longer travel time offsets potential benefits of specialized PSC care. We used real-world US road network information for travel time calculations and evaluated the association of 7-day and 30-day case-fatality rates with receiving care in a PSC using an instrumental variable analysis based on the differential travel time to a PSC vs a non-PSC institution.

Key Points

Question How much does the increased risk of prolonged travel time offset benefits of specialized Primary Stroke Center (PSC) care?

Findings In a retrospective cohort study of Medicare beneficiaries with stroke admitted to a hospital between 2010 and 2013, we found that admission to PSCs was associated with lower 7-day and 30-day case fatality. Receiving treatment in PSCs was associated with a 30-day survival benefit for patients traveling less than 90 minutes, but traveling at least 90 minutes offset any benefit of PSC care.

Meaning Traveling at least 90 minutes to receive care offset the 30-day survival benefit of PSC admission.

Methods

Cohort Creation

This retrospective cohort study was approved by the Dartmouth College Committee for Protection of Human Subjects. Informed consent was waived because we used deidentified data. We used data from a 100% sample of Medicare beneficiaries enrolled in fee-for-service programs or non-risk-bearing health maintenance organizations from January 1, 2010, to December 31, 2013, to identify stroke cases, classified as *International Classification of Diseases, Ninth Revision, Clinical Modification* (*ICD-9-CM*) primary inpatient codes 430.xx, 431.xx, 433.xx, or 434.xx, in inpatient Medicare claims. Exclusion criteria are shown in the eFigure in the Supplement.

Data Sources

A PSC certification is awarded by TJC based on guidelines from the Brain Attack Coalition and the American Heart Association/American Stroke Association. The list of TJC-certified PSCs is publicly available and was accessed via the web for the year 2010 (http://www.jointcommission.org). Admission to a PSC was determined by the certification status of the first hospital to which the patient was admitted and not by subsequent transfers.

Although we had no information on the patient's location at the time of the stroke, the Framingham Study[16] has demonstrated that most strokes happen at home. Population-weighted zip code centroids (points) were used to represent patient origins (2010 data; Maponics).

Latitude and longitude coordinates of hospitals using the 2010 American Heart Association hospital file were used as possible destinations. Primary Stroke Center locations were matched to American Heart Association hospital locations. All zip code centroids were referenced to the WGS84 datum.

Outcome and Covariates

Our primary outcomes were 7-day and 30-day postadmission case fatality. The date of death was determined based on the Medicare denominator file. Age categories (65-69, 70-74, 75-79, 80-84, and 85-99 years), race/ethnicity categories (white, black, Asian, and other based on self-reporting), and stroke type (ischemic, intracerebral hemorrhage, and subarachnoid hemorrhage) were recorded. We created quintiles of zip code income based on a 5-year panel (2007-2011) of the American Community Survey. Poverty rate (based on American Community Survey data) was also included to reflect the differing distribution of income within the zip code.

Comorbidities for which outcomes were adjusted (eTable 1 in the Supplement) included myocardial infarction, cardiac arrhythmia, congestive heart failure, hyperlipidemia, coagulopathy, hypertension, peripheral vascular disease, tobacco use, type 1 and type 2 diabetes mellitus, and chronic renal failure. Comorbidities were determined based on the immediately prior 6-month lookup period. Hierarchical condition categories (HCCs) during the 6 months before admission were created based on the SAS software code provided by the Centers for Medicare & Medicaid Services. While the purpose of HCCs was to create a risk-adjustment approach for expenditures, they are also a highly predictive measure of case fatality.[17] The HCCs were divided into quintiles for the analysis. We used *ICD-9-CM* codes to identify the use of thrombolytics (code 99.10) and mechanical thrombectomy (code 39.74).

Assessment of Ground Travel Times

Street-level network data (StreetMap North America, version 10.2; Esri) were used to calculate the optimal travel time routes. Travel time paths and their distances between origin and destination points were calculated to find the optimal routes using a software program (ArcGIS with the Network Analyst extension; Esri). Total travel time calculations were adjusted for population density[12] (eMethods in the Supplement).

To comply with Centers for Medicare & Medicaid Services reporting requirements, a minimum of 11 patients with stroke per zip code was required for maps showing geographic location of patients with stroke. The patterns are similar to those with no minimum cell size.

Statistical Analysis

The primary analysis examined the association of receiving treatment in a PSC with the 7-day and 30-day case-fatality rates, with all analysis done at the individual patient level. Classic observational techniques are limited by nonrandom selection of patients to hospitals. For example, if patients with more unobserved confounding factors are more likely to be transferred to PSCs, the estimated benefit of PSCs will be biased downward. We attempted to address this unmeasured confounding using an instrumental variable analysis, which has been used in multiple prior studies[18-20] of comparative effectiveness research.

Given the likelihood that patients with stroke will be taken to the nearest hospital, we use the differential travel time of the patient to the closest PSC vs the closest non-PSC institution as a "natural randomization" to assign patients to a PSC (treatment) or non-PSC (control) institution. It is calculated by subtracting the travel time of the patient's location to the closest PSC from the travel time of the patient's location to the closest non-PSC institution. Differential travel time is the most widely accepted instrument used in the literature and is a strong predictor of hospital admission.[18,21,22] The standard rule[23] for a strong instrument is that the *F* statistic for the association of the instrument with exposure exceeds 10. In our case, it exceeded 1600 for all analyses.

The second key assumption is that our instrument is not associated with unmeasured health status (exclusion restriction criterion). We consider the plausibility of this assumption by testing whether those living closer to PSCs have similar underlying measured illness compared with those living farther from PSCs. For this purpose, we used our full set of risk adjusters to estimate predicted mortality based on factors like age, HCC scores, stroke type, and others. We then compared our mortality risk "index" between the half of the sample living closest to PSCs and the half living farthest away, clustered at the regional (hospital referral region) level.

Before controlling for unmeasured confounders, we investigated the association of PSC admission with mortality using a probit regression controlling for all known confounders in our data. Subsequently, our instrumental variable analysis model was based on a 2-stage approach with a probit function in the second stage to account for the binary dependent variable. Probit is similar to a logistic regression but allows an estimate of the differential probability of the outcome (rather than an odds ratio) by calculating the marginal effects (partial derivative) after adjusting for all independent variables.[24] For sensitivity analysis, we also considered an instrumental variable Poisson model to estimate the risk ratios. In all these analyses, we controlled for the sociodemographic and comorbidity variables mentioned previously, including stroke type.

To investigate whether the effect of longer travel time offset the benefit of treatment in a PSC, we stratified the analysis above with respect to the following 5 prespecified categories of patient travel time: less than 20 minutes, 20 to 39 minutes, 40 to 59 minutes, 60 to 89 minutes, and at least 90 minutes. Additional sensitivity analysis stratified our baseline models for separate regions of the United States (Midwest, Northeast, West, and South), for older (>75 years) or younger (65-74 years) patients, and for urban or nonurban residence. In post hoc sensitivity analysis, we repeated our analyses for the subgroups of ischemic stroke, intracerebral hemorrhage, and subarachnoid hemorrhage, although our study was not individually powered for these subcategories. We also considered an analysis that excluded hospital transfers. We did not adjust for multiple comparisons.

The mean imputation for patients with missing urbanicity and income data (6.5% of the sample) did not affect the results, so these patients were excluded. Numbers needed to treat were calculated as the inverse of the absolute risk reduction as appropriate. All probability values were the result of 2-sided tests, and the significance level was set at .05. Software programs (SAS, version 10; SAS Institute Inc and Stata, version 14; StataCorp LP) were used for statistical analysis.

Results

Cohort Characteristics

The eFigure in the Supplement shows the creation of our cohort. During the study period, 865 184 Medicare fee-for-service beneficiaries (mean age, 78.9 years; 55.5% female) were seen with a stroke. There were 976 PSCs across the United States, with 466 334 (53.9%) patients from our cohort being treated in PSCs. Almost one-fourth (24.0%) of the cohort resided closer to a PSC than to a non-PSC institution. The distribution of patient characteristics stratified by whether they received treatment in PSCs is summarized in **Table 1**. There was significant regional variation in access to PSCs, as shown in the **Figure**.

Differences in interventions and hospitalization characteristics between patients admitted to PSCs and those admitted to non-PSC institutions are summarized in eTable 2 in the Supplement. Patients admitted to a PSC were more likely to receive intravenous tissue plasminogen activator (6.0% vs 2.8%) or undergo mechanical thrombectomy (1.0% vs 0.2%) for ischemic stroke compared with their counterparts in non-PSC institutions. Final disposition of patients with stroke is summarized in eTable 3 in the Supplement.

Case Fatality and Treatment in a PSC

In the first 7 days after admission for acute stroke, there were 40 143 (16.5%) deaths among patients hospitalized in PSCs and

Table 1. Patient Characteristics

Variable	Total (N = 476 821)	Treated in Primary Stroke Centers (n = 243 609)	Treated in Non–Primary Stroke Center Institutions (n = 233 212)
Age, mean (SD), y	78.9 (7.9)	78.6 (7.8)	79.1 (7.9)
Male sex, No. (%)	207 417 (43.5)	108 606 (44.4)	99 348 (42.6)
Poverty rate, No. (%)[a]	49 589 (10.4)	23 482 (9.6)	26 120 (11.2)
Race/ethnicity, No. (%)			
White	417 695 (87.6)	213 544 (87.3)	205 227 (88.0)
Black	43 391 (9.1)	22 993 (9.4)	20 523 (8.8)
Asian	6199 (1.3)	3669 (1.5)	2565 (1.1)
Other	9536 (2.0)	4403 (1.8)	4897 (2.1)
Urbanicity, No. (%)			
Urban	239 840 (50.3)	147 989 (60.5)	92 352 (39.6)
Suburban	158 305 (33.2)	81 699 (33.4)	72 727 (31.2)
Rural	78 676 (16.5)	14 921 (6.1)	68 133 (29.2)
Income, mean (SD), $[a]	45 000 (17 000)	47 000 (18 000)	43 000 (16 000)
HCC score, mean (SD)	2.5 (1.4)	2.5 (1.5)	2.4 (1.4)
Comorbidities, No. (%)[b]			
Myocardial infarction	144 000 (30.2)	74 361 (30.4)	69 730 (29.9)
Cardiac arrhythmia	13 017 (2.7)	67 512 (27.6)	63 200 (27.1)
Congestive heart failure	61 987 (13.0)	31 065 (12.7)	31 250 (13.4)
Hyperlipidemia	174 040 (36.5)	94 174 (38.5)	80 225 (34.4)
Coagulopathy	9060 (1.9)	5137 (2.1)	3731 (1.6)
Hypertension	344 742 (72.3)	177 097 (72.4)	168 612 (72.3)
Peripheral vascular disease	41 960 (8.8)	22 259 (9.1)	19 823 (8.5)
Tobacco use	54 358 (11.4)	29 598 (12.1)	24 954 (10.7)
Type 1 or type 2 diabetes mellitus	120 636 (25.3)	60 174 (24.6)	60 653 (26.0)
Chronic renal failure	46 728 (9.8)	23 972 (9.8)	22 855 (9.8)

Abbreviation: HCC, hierarchical condition category.

[a] These variables are based on a 5-year panel (2007-2011) of the American Community Survey.

[b] Comorbidities are based on 12-month look-back before the date of the procedure.

31 097 (13.3%) deaths among patients hospitalized in non-PSC institutions. The corresponding 30-day deaths were 75 151 (30.8%) in PSCs and 61 397 (26.3%) in non-PSC institutions.

In multivariable regression analysis controlling for all health status and sociodemographic factors, admission to a PSC was associated with 0.7% (95% CI, 0.6%-0.8%) higher 7-day case fatality and 0.6% (95% CI, 0.5%-0.7%) higher 30-day case fatality. However, this estimate is potentially biased because it does not control for unmeasured confounding.

To address this limitation of unmeasured confounding, we used differential travel time as an instrument (**Table 2** and eTable 4 in the Supplement). Differential travel time was a strong instrument for PSC admission. When the PSC was at least 1 hour closer than the nearest non-PSC institution, 87.5% of patients were admitted to a PSC. When the PSC was 1 hour farther from the non-PSC institution, only 38.8% of patients were admitted to a PSC. We did not find evidence that those who lived nearest to a PSC were sicker than those living far from a PSC: predicted mortality in the former was 15.8%, while that in the latter was 15.7% (P = .57).

Our analysis suggested that PSC admission was associated with −1.8% (95% CI, −2.1% to −1.4%) lower 7-day case fatality (Table 2). Similarly, PSC admission was associated with −1.8% (95% CI, −2.3% to −1.4%) lower 30-day case fatality. The number needed to treat (NNT) in PSCs to save one life at 30 days after admission for acute stroke was 56 patients.

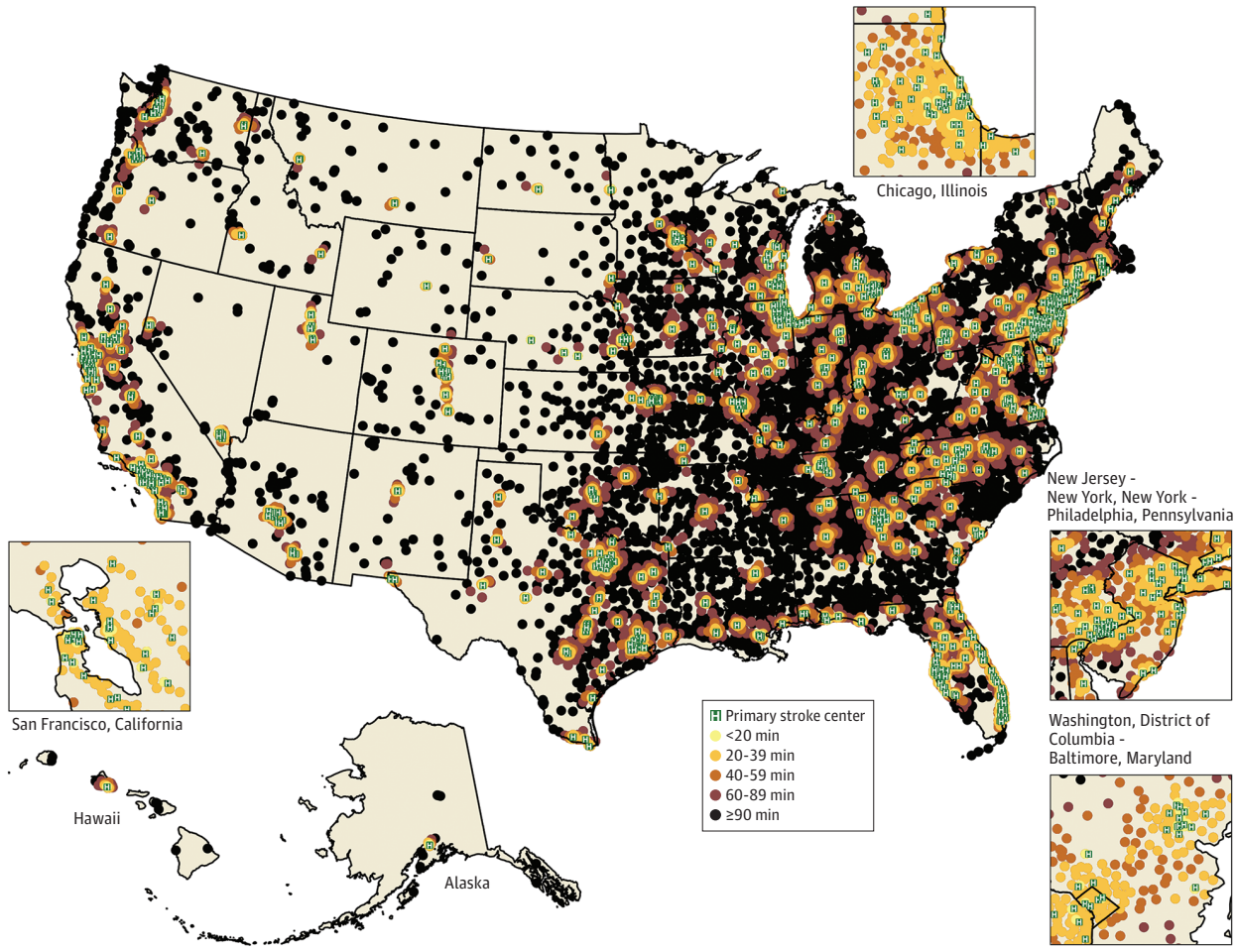
PSC Survival Benefit and Travel Time

Receiving treatment in a PSC was associated with a 30-day survival benefit for patients traveling less than 20 minutes (adjusted difference, 2.7%; 95% CI, 1.5%-3.9% [NNT, 37 patients]), 20 to 39 minutes (adjusted difference, 1.8%; 95% CI, 1.3%-2.2% [NNT, 56 patients]), 40 to 59 minutes (adjusted difference, 2.6%; 95% CI, 0.7%-2.8% [NNT, 38 patients]), and 60 to 89 minutes (adjusted difference, 1.7%; 95% CI, 0.2%-2.4% [NNT, 59 patients]). Traveling at least 90 minutes to receive care yielded no net benefit of PSC admission (adjusted difference, 0.1%; 95% CI −3.1% to 3.3%). Similar associations were observed for 7-day outcomes, with travel time offsetting the effect of PSC admission at 60 minutes (**Table 3**).

Sensitivity Analysis

We considered relative risk estimates for 7-day and 30-day case fatality using an instrumental variable Poisson regression with the same covariates (eTable 2 in the Supplement). The risk ratios for admission to a PSC were 0.82 (95% CI, 0.76-0.88) for 30-day case fatality and 0.70 (95% CI, 0.64-0.78) for 7-day case fatality, implying roughly similar absolute differences in case fatality as those in the primary analysis. We stratified the instrumental variable analysis for case fatality along several dimensions (Table 2). We observed regional variation for the 4 regions of the United States. Estimates stratified by age or urban residence were similar to those at baseline.

Figure. Map of the United States Showing the Shortest Ground Total Time From Patient Zip Code Origin to Primary Stroke Centers Among Medicare Beneficiaries With Stroke Using Road Network Data



Alaska and Hawaii total travel times are derived from geodesic distance because of the limited road network. Green squares with a letter "H" indicate Primary Stroke Centers, while all other dots indicate zip code centroids of various total travel times to the closest Primary Stroke Center.

Table 2. Association of Primary Stroke Center Admission With Outcome Measures

Model	7-Day Mortality		30-Day Mortality	
	Adjusted Difference, % (95% CI)	*P* Value	Adjusted Difference, % (95% CI)	*P* Value
Probit regression[a]	0.7 (0.6 to 0.8)	<.01	0.6 (0.5 to 0.7)	<.01
IV analysis	−1.8 (−2.1 to −1.4)	<.01	−1.8 (−2.3 to −1.4)	<.01
Midwest region IV analysis	−2.6 (−3.5 to −1.8)	<.01	−2.3 (−3.4 to −1.2)	<.01
Northeast region IV analysis	−1.8 (−2.4 to −1.2)	<.01	−1.7 (−2.4 to −0.9)	<.01
West region IV analysis	−1.8 (−3.2 to −0.5)	<.01	−3.3 (−5.1 to −1.6)	<.01
South region IV analysis	−0.8 (−1.3 to −0.3)	<.01	−1.0 (−1.6 to −0.4)	<.01
Patient age >75 y IV analysis	−1.9 (−2.3 to −1.4)	<.01	−1.8 (−2.4 to −1.2)	<.01
Patient age 65-64 y IV analysis	−1.4 (−1.9 to −0.9)	<.01	−1.6 (−2.2 to −0.9)	<.01
Urban residence IV analysis	−1.1 (−1.6 to −0.5)	<.01	−0.7 (−1.4 to 0.1)	.069
Nonurban residence IV analysis	−2.1 (−2.5 to −1.7)	<.01	−2.4 (−3.0 to −1.8)	<.01

Abbreviation: IV, instrumental variable.

[a] This model controls for all sociodemographic and comorbidity variables. All other models use a 2-stage approach, with a probit function in the second stage using the differential travel time of the patient to a Primary Stroke Center vs a non–Primary Stroke Center institution as an instrument.

In post hoc sensitivity analyses, we repeated our main instrumental variable analyses in subgroups stratified by stroke type, recognizing that our study was not specifically powered to address this question (eTable 5 in the Supplement). For patients with ischemic stroke, PSC admission was associated with 1.7% (95% CI, −2.0% to −1.4%) lower 7-day case fatality. Primary Stroke Center admission was associated with 2.8% (95% CI, −9.5% to 3.9%) lower 7-day case fatality for patients

Table 3. Survival Benefit of Primary Stroke Center Admission Stratified by Travel Time[a]

	7-Day Survival Benefit		30-Day Survival Benefit	
Travel Time, min	Adjusted Difference, % (95% CI)	*P* Value	Adjusted Difference, % (95% CI)	*P* Value
<20	2.0 (1.2 to 2.9)	<.01	2.7 (1.5 to 3.9)	<.01
20 to 39	1.6 (1.2 to 1.9)	<.01	1.8 (1.3 to 2.2)	<.01
40 to 59	1.9 (2.5 to 1.3)	<.01	2.6 (0.7 to 2.8)	<.01
60 to 89	0.7 (−0.1 to 1.5)	.10	1.7 (0.2 to 2.4)	<.01
≥90	1.3 (−1.2 to 3.9)	.31	0.1 (−3.1 to 3.3)	.95

[a] Values represent probability differences in a 2-stage approach, with a probit function in the second stage using the differential travel time of the patient to a Primary Stroke Center vs a non–Primary Stroke Center institution as an instrument.

with subarachnoid hemorrhage and 1.3% (95% CI, −3.9% to 1.4%) lower 7-day case fatality for patients with intracerebral hemorrhage, although the latter 2 associations were not significant. Last, excluding transfers did not change our results (eTable 5 in the Supplement).

Discussion

Among Medicare beneficiaries, treatment in a PSC was associated with decreased 7-day and 30-day postadmission case fatality compared with noncertified institutions. Traveling at least 90 minutes to receive care offsets the 30-day survival benefit of PSCs (60 minutes for the 7-day survival benefit). These results are statistically significant and are clinically significant, implying one life saved for every 56 treated in a PSC. With the current distribution of PSCs, 16.4% of patients are located at least 90 minutes by ground transportation from the nearest PSC.

Prior studies have investigated the association of hospitalization in PSCs with stroke outcomes. Lichtman et al,[5] in a national cohort of patients with ischemic stroke, demonstrated that hospitalization in PSCs was associated with slightly lower 30-day case fatality compared with noncertified hospitals, although the difference was not statistically significant. In addition, in a separate study,[4] Lichtman and colleagues showed that patients with hemorrhagic stroke receiving care in PSCs had significantly improved 30-day case fatality compared with their counterparts admitted to non-PSC institutions. The authors[4,5] recognized that the major limitation of their results is the presence of unmeasured confounding because of selection bias.[18,19] Proximity, severity of disease, and insurance coverage can be some of the factors that might affect patient disposition.

To address these limitations and account for such confounders, we used an instrumental variable analysis using the differential travel time as an instrument. Differential travel time has been used before in similar observational studies[18,19] of comparative effectiveness. In a regional cohort, Xian et al[6] used an instrumental variable analysis to demonstrate superior outcomes for patients with ischemic stroke hospitalized in local centers of excellence. Their analysis focused on locally certified hospitals (different from the PSCs, which are certified by TJC) and is specific to New York State.

Given the potential for improved stroke outcomes with PSC admissions, identifying the optimal time frame to receive care in these institutions is of central importance. To our knowledge, this question has not been addressed before in the literature. Our time calculations build on the work by Albright et al[12] and others[13,14] who investigated the access of all US residents (regardless of age and whether they had a stroke) to PSCs. The advantage of our analysis lies in using a large comprehensive cohort of patients with stroke. In addition, contrary to prior work[12-14] using straight-line distance calculations of ground travel time, we used real-world road network data for the conterminous United States contemporary to the study years. These data simulate closely the ground path through which the patient could reach a PSC, taking into account the effect of natural obstacles like mountains or rivers.

Travel times of at least 90 minutes appear to negate 30-day mortality gains arising from admission to a PSC. As suggested by our finding of higher thrombolytic and mechanical thrombectomy rates in PSCs, superior outcomes in PSCs likely reflect organized, disease-specific, efficient care, as well as the timely administration of the optimal treatments and efficient blood pressure optimization. Among those living between 60 and 89 minutes from a PSC, the finding that PSC benefits arise only after 30 days (but not at 7 days) could reflect additional postacute services available through PSCs.

The access map (Figure) of the United States demonstrates that a significant proportion of patients with stroke are outside of this 90-minute window. These access disparities have stimulated discussions about more thoughtful creation of stroke centers within the confines of a single state[25] or nationally.[12] The establishment or certification of new centers can be prohibitive from a cost perspective. Building on the experience of trauma care, the optimal use of air services with the existing PSC locations could expand access within this time frame for almost all patients with stroke. This alternative is just one approach from a plethora of available options to address disparities in access and follow the recommendations of the Institute of Medicine[26,27] to maximize the use of local referral centers. Other potential solutions include expanding telemedicine applications, enhancing smaller hospitals into Acute Stroke-Ready Hospitals, and creating broader hospital networks.[28,29] Further investigations are necessary to identify the best combination of approaches to treat patients with stroke.

The present study has limitations. First, coding inaccuracies can affect our estimates, although several studies[30,31] have demonstrated that coding for stroke has good association with medical record review. Second, residual confounding can bias our results, for example because of differences in time from stroke onset and because of stroke severity unmeasured in the Medicare claims data. We attempted to minimize such bias in an instrumental variable analysis,

which simulates randomization by balancing the treatment and control groups in terms of unmeasured confounders. It is reassuring that our predicted mortality index was so similar for the group living near a PSC (most likely admitted to a PSC) and the control group living far from a PSC (least likely to be admitted to a PSC).

A third limitation is that we cannot necessarily identify what it is about PSCs that reduces mortality rates. These variables could include factors like emergency department delays, availability of telestroke, timing of interventions, withdrawal of care, rehabilitation during hospitalization, and the use of emergency medical transportation. Fourth, our data are based on the Medicare population, with potentially different results for the commercially insured. However, three-quarters of all strokes happen in patients 65 years or older, most of whom are covered by Medicare.[1]

Fifth, we underestimate the potential risks of longer travel time in ambulances because patients who die in the ambulance may not appear in the Medicare claims data. In a recent study[32] of urban patients with stroke treated in ambulances, the incidence of any death in the ambulance was only 0.2% (12 of 7098 patients), suggesting that the incremental effects of longer ambulance rides would not reverse our findings. Sixth, assigning populations to zip code centroids may give falsely low travel times for some patients, while overestimating travel times in others. To adjust for this limitation, we integrated in our travel time calculations previously validated indicators of average traffic delays based on the urbanicity of the patient's residence. Seventh, we recognize that our estimate of no benefit for patients traveling at least 90 minutes carries with it a wide 95% CI. Eighth, the scope of this analysis included only PSCs certified by TJC and excluded state-certified hospitals or those participating in national quality improvement programs. Ninth, we had no information on the neurologic status of our patients at the time of discharge; therefore, we could not analyze the differences between PSCs and noncertified institutions for these outcomes. Tenth, causality cannot easily be established based on ecologic data, despite the use of an instrumental variable analysis.

Conclusions

Among Medicare beneficiaries with stroke, treatment in a PSC was associated with decreased 7-day and 30-day postadmission case-fatality rates. Traveling at least 90 minutes to receive care offset the 30-day survival benefit of PSCs. Further investigations are necessary to identify the best combination of approaches to improve access to centers of excellence and stroke outcomes.

ARTICLE INFORMATION

Accepted for Publication: April 27, 2016.

Published Online: July 25, 2016. doi:10.1001/jamainternmed.2016.3919.

Author Contributions: Drs Bekelis and Skinner had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.
Study concept and design: Bekelis, Skinner.
Acquisition, analysis, or interpretation of data: Bekelis, Marth, Wong, Zhou, Skinner.
Drafting of the manuscript: Bekelis, Marth, Birkmeyer, Skinner.
Critical revision of the manuscript for important intellectual content: Bekelis, Wong, Zhou, Birkmeyer, Skinner.
Statistical analysis: Bekelis, Wong, Zhou, Birkmeyer, Skinner.
Obtained funding: Skinner.
Administrative, technical, or material support: Marth, Skinner.

Conflict of Interest Disclosures: None reported.

Funding/Support: This study was funded by grant P01-AG19783 from the National Institute on Aging and grant U01-AG046830-01 from the National Institutes of Health Common Fund.

Role of the Funder/Sponsor: The funders had no role in the design and conduct of the study; the collection, management, analysis, and interpretation of the data; the preparation, review, or approval of the manuscript; and the decision to submit the manuscript for publication.

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Invited Commentary

Admitting the Patient With Acute Stroke to the Right House—Lessons From the Sorting Hat of Hogwarts

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The goal of any prehospital sorting function is to allocate patients to the most appropriate destination that will maximize their outcomes as defined by their preferences, goals, needs, and resources. In much the same way, the Sorting Hat at Hogwarts School of Witchcraft and Wizardry in J. K. Rowling's world of Harry Potter seeks to place each student in the proper "house." Just as there are competing schools of wizardry, there are also multiple organizations[1] that seek to certify stroke centers by differing criteria, although The Joint Commission (JC) Primary Stroke Center (PSC) program is by far the oldest and largest.

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In their article in this issue of *JAMA Internal Medicine*, Bekelis and colleagues[2] examine the effect of patients with stroke being "sorted" to admission at a JC PSC vs a non-JC PSC on the outcome of death by 7 and 30 days. Their main interest was in determining the additional travel distance necessary beyond the hospital nearest to a patient's home for admission to a PSC after which no difference in outcomes would be evident. Among patients who entered this complex maze of stroke care from 2010 to 2013, they found higher mortality after multivariable adjustment for patients assigned to a house that was JC PSC certified vs one that was not, but this effect reversed when using instrumental variable analysis to account for unmeasured confounding. After 90 minutes of added travel, no benefit was gained by admission to a JC PSC. Within the limits of their Medicare (Centers for Medicare & Medicaid Services [CMS]) fee-for-service claims data source, they did an elegant job of trying to control for measured and unmeasured confounding introduced by the nonrandom allocation of patients.

Ischemic stroke and hemorrhagic stroke have different clinical trajectories: hemorrhagic stroke has greater mortality, less diagnostic uncertainty, greater likelihood of transfer, and relatively few patients for whom treatment in the "golden hour" dramatically alters the outcome. Unlike many serious acute diseases, stroke mortality is largely predicted by one (ie, stroke severity) rather than many covariates. The CMS risk-standardized model of hospital rankings on 30-day ischemic stroke mortality does not adjust for stroke severity. Addition of this unmeasured confounder has a dramatic effect on reclassification of hospital performance,[3] and all measures of performance that relate to functional outcomes or mortality must include severity. In models of in-hospital mortality using data in the Get With The Guidelines-Stroke Program,[4] almost all of the fully adjusted model's C statistic is due to the National Institutes of Health Stroke (NIHSS) score alone. Fortunately, the *International Statistical Classification of Diseases, 10th Revision* will soon include a mechanism for collecting NIHSS severity into claims data, and the CMS has proposed modified versions of its 30-day risk-standardized measures to include these data.

Although frequently disabling, stroke is a high-impact low-frequency event in the prehospital or emergency department (ED) setting. Estimates suggest that stroke represents less than 5% of emergency medical services (EMS) transports.[5] Recent data suggest that 15% of ED visits resulted in hospital