Published in final edited form as:

J Clin Neurosci. 2019 February ; 60: 12–16. doi:10.1016/j.jocn.2018.10.031.

Emergency medical services for acute ischemic stroke: hub-and-spoke model versus exclusive care in comprehensive centers

Kimon Bekelis, M.D.^{1,2,3,4}, Symeon Missios, M.D.^{3,5}, Shannon Coy, M.D.⁶, Bruce Mayerson, M.D.^{1,3}, and Todd A. MacKenzie, Ph.D.^{2,3,4,6}

¹Neuroscience Service Line, Catholic Health Services of Long Island, Melville, NY

²The Dartmouth Institute for Health Policy and Clinical Practice, Lebanon, NH

³Population Health Research Institute of New York at CHS, Melville, NY

⁴Geisel School of Medicine at Dartmouth, Hanover, NH

⁵Department of Neurosurgery, Thomas Jefferson University Hospital, Philadelphia, PA

⁶Department of Community and Family Medicine, Dartmouth-Hitchcock Medical Center, Lebanon, NH

Abstract

Background.—The emergent disposition of acute stroke patients remains an issue of debate. We investigated whether a hub-and-spoke model was associated with worse stroke outcomes when compared to care exclusively in comprehensive centers.

Methods.—We performed a cohort study of all acute ischemic stroke patients who were hospitalized in endovascular-capable facilities, and were registered in the New York Statewide Planning and Research Cooperative System (SPARCS) database from 2009–2015. We examined the association of transfer status (transfer to endovascular capable hospitals versus initial treatment in these facilities) with inpatient case-fatality, discharge to a facility, and length of stay (LOS). An instrumental variable analysis was used to control for unmeasured confounding and simulate a randomized trial.

Results.—During the study period, 128,122 acute stroke patients met inclusion criteria. Instrumental variable analysis demonstrated that patients transferred to endovascular-capable hospitals did not have higher case-fatality (Adjusted difference, 4.4%; 95% CI, –0.1% to 9.0%), rate discharge to a facility (Adjusted difference, –2.3%; 95% CI, –5.2% to 0.6%), or longer LOS (Adjusted difference, 4.2; 95% CI, –2.2 to 10.1) in comparison to patients presenting for initial treatment in these facilities. The same associations were present when restricting the cohort to patients receiving intravenous tissue plasminogen (IV-tPA) and to patients receiving mechanical thrombectomy.

Corresponding Author: Kimon Bekelis, M.D., The Dartmouth Institute for Health Policy and Clinical Practice, One Medical Center Drive, Lebanon, NH 03755, T. 6036505110, F. 6036504547, kbekeles@gmail.com.

Conflicts of interest

The authors have no conflicts to disclose

Conclusions.—Using a comprehensive all-payer cohort of acute ischemic stroke patients in New York State we demonstrated that patients treated in a hub-and-spoke model were not associated with worse outcomes than patients receiving care exclusively in comprehensive institutions. This needs to be taken into consideration when considering acute emergency services in this setting.

Keywords

acute ischemic stroke; transfer; center of excellence; hub-and-spoke; endovascular treatments; SPARCS

INTRODUCTION

The disposition of acute ischemic stroke patients remains an issue of debate among EMS (Emergency Medical Service) providers and physicians.(1, 2) Recent evidence, demonstrating the value of mechanical thrombectomy for large vessel occlusion (LVO), has shifted the paradigm of care delivery in this population.(3–5) In an effort to maximize timely access to these services, some have promoted the notion of bypassing non-endovascular capable hospitals for patients likely to have an LVO.(6) This approach puts the burden on EMS to recognize signs of LVO, through published pre-hospital grading scales.(7–9) However, this proposition has been met with significant resistance from physicians, pointing out the significant risk of misclassification.(10–14) Of all patients presenting with neurologic compromise only a small minority suffers from an LVO, while available pre-hospital grading scales have only moderate sensitivity and specificity, even in controlled settings. Lastly, they put forth evidence demonstrating that every minute delay in the administration of IV-tPA, which can result from bypassing IV-tPA capable facilities, is associated with significant morbidity and mortality.(15)

Prior studies attempting to shed light in this controversy have not been able to demonstrate superior outcomes for patients treated exclusively in comprehensive facilities.(5, 16–20) The main limitation of these retrospective analyses is the lack of control for unmeasured confounding, stemming from the non-random allocation of patients to particular hospitals. There has been no previous investigation attempting to answer this question in a comprehensive all-payer cohort of acute stroke patients, while controlling for unmeasured confounding.

We used the New York Statewide Planning and Research Cooperative System (SPARCS) (21) to examine the association of transfer status (transfer to endovascular capable hospitals versus initial treatment in these facilities) with inpatient case-fatality, discharge to a facility, and length of stay (LOS). An instrumental variable (IV) analysis was used to control for unmeasured confounding and simulate the effect of randomization.

METHODS

New York Statewide Planning and Research Cooperative System (SPARCS)

This study was approved by our institutional Committee for Protection of Human Subjects. This study is based on de-identified data and therefore the consent process was waived by

the committee. All patients who were hospitalized for acute ischemic stroke in endovascular-capable hospitals, and were registered in the SPARCS (New York State Department of Health, Albany, NY)(21) database between 2009 and 2015 were included in the analysis. For these years, SPARCS contains patient-level details for every hospital discharge, ambulatory surgery, and emergency department admission in New York State as coded from admission and billing records. More information about SPARCS is available at <https://www.health.ny.gov/statistics/sparcs/>.

Cohort Definition

In order to establish the cohort of patients, we used *International Classification of Disease-9-Clinical Modification* (ICD-9-CM code 433.x1, 434.x1) codes to identify adult (18 years and older) patients in the database, who were hospitalized for acute ischemic stroke between 2009 and 2015. Stroke related intervention was also recorded and defined as endovascular mechanical thrombectomy (ICD-9 code 39.74), or administration of intravenous t-PA (ICD-9 code 99.10).

Outcome variables

The primary outcome variable was case-fatality during the initial hospitalization. Secondary outcomes were LOS during the initial hospitalization and discharge to a facility. The latter included all locations of disposition other than the patient's home.

Exposure variables

The primary exposure variable was whether the stroke patient was transferred to an endovascular-capable hospital from another facility.

Covariates (Table S1) used for risk-adjustment were age, gender, race (African-American, Hispanic, Asian, Caucasian, other), insurance (private, Medicare, Medicaid, uninsured, other), IV-tPA administration, and mechanical thrombectomy.

The comorbidities used for risk adjustment were diabetes mellitus (DM), smoking, chronic lung disease, hypertension, hypercholesterolemia, peripheral vascular disease (PVD), congestive heart failure (CHF), coronary artery disease (CAD), history of ischemic stroke, history of transient ischemic attack (TIA), alcohol abuse, obesity, chronic renal failure (CRF), and coagulopathy. Only variables that were defined as "present on admission" were considered part of the patient's comorbidity profile.

Statistical analysis

The association of transfer status with our outcome measures was examined using an instrumental variable analysis. Patients transferred to an endovascular-capable facility from another hospital versus presenting to that facility from the field were non-randomly directed this way. In order to account for this unmeasured confounding, and to simulate the effect of randomization, we used an instrumental variable analysis, an econometric technique.(22) The percentage of transferred stroke patients in each endovascular-capable hospital was used as an instrument. This observational technique has been used before by clinical researchers, to answer comparative effectiveness questions for different interventions or treatment

facilities. The goal is to simulate randomization, especially when the baseline functional characteristics of the patients are unknown (similar to our application).(23–25)

A good instrument is not associated with the outcome other than through the exposure variable of interest (a requirement known as the exclusion restriction criterion).(26) In our case it is unlikely that our instrument would be associated with case-fatality in any way other than the choice of treatment facility. A two stage least squares (2SLS) method was used for the calculation of the coefficients. The value of the F statistic in the first stage of the 2SLS approach was 110, which is consistent with a strong instrument (F statistic>10), based on a practical rule.(22)

A probit regression was used for the categorical outcomes (case-fatality, discharge to a facility),(27) and a linear regression for the linear outcomes (LOS). The values of LOS were positively skewed and therefore were log transformed for the purpose of the analysis. The covariates used for risk adjustment in these models were: age, gender, race, insurance, provider case-specific volume, IV-tPA administration, mechanical thrombectomy, and all the comorbidities mentioned previously. Since the coefficients produced by the probit function are not easily interpretable, we used the marginal effects of our independent variables instead.

In order to demonstrate the robustness of our data in a pre-specified sensitivity analysis, we restricted our cohort to patients receiving IV-tPA, and in another analysis in patients undergoing mechanical thrombectomy. The direction of the observed associations did not change.

Regression diagnostics were performed for all models. All results are based on two sided tests, and the level of statistical significance was set at 0.05. This study, based on 128,122 patients, has sufficient power (80%) at a 5% type I error rate to detect differences in case-fatality, as small as 2.47%. %. Statistical analyses were performed using Stata version 13 (StataCorp, College Station, TX), the 64-bit version of R.3.1.0 (R Foundation for Statistical Computing), and SPSS version 23 (IBM, Armonk, NY).

RESULTS

Patient characteristics

In the selected study period there were 128,122 patients hospitalized in endovascular-capable hospitals after an acute ischemic stroke (mean age was 70.4 years, with 50.2% females), who were registered in SPARCS. 113,672 (88.7%) presented initially and were treated in endovascular-capable centers, whereas 14,450 (11.3%) were transferred to these institutions from other facilities. The characteristics of the two cohorts at baseline can be seen in Table 1.

Inpatient case-fatality

Overall, 1,770 (12.25%) inpatient deaths were recorded among transferred patients and 8,295 (7.30%) among those not transferred. Transfer to an endovascular-capable center was not associated (Table 2) with higher case-fatality in comparison to exclusive treatment in

these facilities (Difference, 4.4%; 95% CI, -0.1% to 9.0%) in an instrumental variable analysis. This persisted in an instrumental variable analysis restricting our cohort to only patients that received IV-tPA (Adjusted difference, 3.5%; 95% CI, -1.4% to 8.4%), or those that underwent mechanical thrombectomy (Adjusted difference, 2.9%; 95% CI, -2.1% to 7.8%).

Length-of-stay

The average LOS was 12.65 days (SD 19.4) among transferred patients, and 8.46 days (SD 13.4) among those not transferred. Transfer to an endovascular-capable center was not associated (Table 2) with longer LOS in comparison to exclusive treatment in these facilities (Adjusted difference, 4.2; 95% CI, -2.2 to 10.1) in an instrumental variable analysis. This persisted in an instrumental variable analysis restricting our cohort to only patients that received IV-tPA (Adjusted difference, 3.5; 95% CI, -2.9 to 9.4), or those that underwent mechanical thrombectomy (Adjusted difference, 3.9; 95% CI, -2.5 to 9.9).

Discharge to a facility

Overall, 7,727 (60.9%) patients were discharged to a facility among those transferred and 54,815 (52.0%) among those not transferred. Transfer to an endovascular-capable center was not associated (Table 2) with higher rate of discharge to a facility in comparison to exclusive treatment in these facilities (Adjusted difference, -2.3%; 95% CI, -5.2% to 0.6%) in an instrumental variable analysis. This persisted in an instrumental variable analysis restricting our cohort to only patients that received IV-tPA (Adjusted difference, -1.9%; 95% CI, -4.8% to 1.0%), or those that underwent mechanical thrombectomy (Adjusted difference, -2.2%; 95% CI, -4.6% to 1.3%).

DISCUSSION

Using a comprehensive all-payer cohort of acute ischemic stroke patients admitted to endovascular-capable facilities in New York State we did not identify an association of transfer from another hospital with increased case-fatality, rate of discharge to a facility, and LOS. These results were consistent across sensitivity analyses that restricted our cohort to patients undergoing specific treatments and therefore of similar stroke severity. Optimizing stroke outcomes is dependent upon restructuring care delivery in order to expedite the administration of patient specific treatments.(2) To achieve that, some support a drip-and-ship approach in a hub-and-spoke model, whereas others(6) promote exclusive care in comprehensive centers, while bypassing local IV-tPA capable hospitals. However, researchers have not attempted to answer this controversy before in a way that accounts for unmeasured confounders.

The optimal disposition of acute stroke patients is at the core of efficient emergency services for this population.(2) Several researchers have demonstrated that treatment in IV-tPA capable hospitals is associated with superior outcomes.(28, 29) In that setting, bypassing non Primary Stroke Centers (PSC) makes sense if the closest PSC is within 90 minutes of the patient's location, as demonstrated by Bekelis et al in a national study of over 800,000 stroke victims. However, wide access disparities exist for these facilities.(30) Those are further

intensified when considering only endovascular-capable hospitals.(31) There is heated debate on whether endovascular-capable hospitals should be favored, while bypassing IV-tPA capable facilities.

Proponents of this approach claim that pre-hospital identification of LVO can be achieved with existing tools and such patients can be redirected with minimal additional travel times. (6, 32, 33) In support of this notion, bypassing local facilities to direct stroke patients to comprehensive stroke centers was theoretically modeled to add less than 15 minutes of travel time for the majority of patients in the Cincinnati metropolitan area. This approach is based on the premise that bypassing local hospitals can result in faster revascularization and superior outcomes for stroke patients with LVO. However, there is limited evidence backing this claim.

On the contrary, others support the need for evaluation of patients with neurologic symptoms in the closest IV-tPA capable facility, and further transfer to an endovascular capable center for eligible patients with LVO.(4, 33) They highlight the risks of misclassification from using pre-hospital stroke scales, which can result in delays of treatment for patients with other neurologic emergencies, including intracranial hemorrhages, brain tumors, seizures etc. Several analyses have demonstrated the shortcomings of these scales, and particularly their limited specificity.(11, 12, 14, 34) A meta-analysis showed that multiple validated scales missed up to 30% of strokes on the field.(10) Additionally, prolonged travel times will inevitably result in delays in IV-tPA administration, which is still the only treatment available for the majority of stroke patients. Saver et al, in a landmark study, demonstrated that 15-minute incremental delays in IV-tPA administration result in significantly worse functional outcome.(15)

Several investigators have demonstrated that transferred stroke patients have similar outcomes to their directly admitted counterparts. Barlinn et al,(16) studying a single hospital network, demonstrated that endovascular treatment for stroke patients transferred from remote hospitals is equitable to patients admitted directly to the tertiary hospital. Similarly, investigators demonstrated superior outcomes from the drip-and-ship approach in the setting of well-organized, efficient PSC with door-to-needle times of less than 30 minutes, in a multi-state study.(5) Ionita et al(17) have demonstrated similar quality and efficiency in IV-tPA administration for the hub and the spoke hospitals in a single multi-institution network. Additionally, hub-and-spoke models have been associated with superior stroke outcomes in other countries.(19) The key to efficiency in such models is rapid inter-facility transfer.(20) Although real world data from Australia demonstrated long transfer times between hospitals, similar analyses in New York have highlighted effective solutions to time barriers.(18) However, these prior studies have significant methodologic drawbacks. They mainly stem from the lack of rigorous control for measured and unmeasured confounders, particularly the fact that patients were non-randomly selected for either treatment center. The lack of accounting for this selection bias significantly restricts the interpretation of these findings.

Our study purposefully addresses many of these methodologic limitations. First, we created a comprehensive statewide cohort, in order to accurately represent practice in the community. Second, we used advanced observational techniques to control for confounding.

An instrumental variable analysis was used to control for unmeasured confounders (mainly the a priori selection of treatment facility), and simulate the effects of randomization. The instrumental variable analysis is expected to control for selection bias and report results for patients of similar functional status. Previous studies have used this technique to compare the performance of different institutions. Bekelis et al(35) demonstrated that Primary Stroke Centers (PSC) offer a survival benefit for stroke patients, using the differential distance to a PSC as an instrument. Our results were robust across different cohort definitions, supporting the validity of the observed associations.

Our study has several limitations. Residual confounding could account for some of the observed associations. However, this is minimized to the extent that we are using a good instrument for transfers. The F statistic in our analysis suggests a strong instrument. In addition, coding inaccuracies will undoubtedly occur and can affect our estimates. However, coding for stroke has demonstrated good sensitivity against medical record review. Although SPARCS includes all hospitals from the entire New York State, the generalization of this analysis to the entire US population is uncertain. SPARCS does not provide any clinical information on the functional status of the patients, which can affect the choice of institution. However, the use of the instrumental variable analysis is attempting to control for unknown confounders such as these, and has been used before in SPARCS.(23–25)

Additionally, we were lacking post-hospitalization, and long-term data on our patients. Quality metrics are also not available through SPARCS, and therefore we cannot compare the two patient populations on these outcomes. The definitive comparison of the two hospital settings on functional outcomes can only be done in prospective registries. In this direction, the NeuroPoint Alliance has created the first neurovascular registry, with results expected in the near future.(36) Finally, causality cannot be definitively established based on observational data, despite the use of advanced techniques, such as the instrumental variable analysis.

Conclusions

The emergent disposition of acute stroke patients remains an issue of debate, especially in light of new evidence underscoring the value of endovascular interventions. We investigated whether a hub-and-spoke model was associated with worse stroke outcomes when compared to care exclusively in comprehensive centers. Using a comprehensive all-payer cohort of acute ischemic stroke patients in New York State we demonstrated that patients treated in a hub-and-spoke models were not associated with worse outcomes than patients receiving care exclusively in comprehensive institutions. This needs to be taken into consideration when considering acute emergency services in this setting.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

Funding: Supported by grants from the National Institute on Aging (PO1- AG19783), the National Institutes of Health Common Fund (U01-AG046830), and the National Center for Advancing Translational Sciences (NCATS)

of the NIH (Dartmouth Clinical and Translational Science Institute-UL1TR001086). The funders had no role in the design or execution of the study.

REFERENCES

1. Ng FC, Low E, Andrew E, Smith K, Campbell BCV, Hand PJ, et al. Deconstruction of Interhospital Transfer Workflow in Large Vessel Occlusion: Real-World Data in the Thrombectomy Era. *Stroke* 2017;48(7):1976–9. [PubMed: 28512170]
2. McTaggart RA, Ansari SA, Goyal M, Abruzzo TA, Albani B, Arthur AJ, et al. Initial hospital management of patients with emergent large vessel occlusion (ELVO): report of the standards and guidelines committee of the Society of NeuroInterventional Surgery. *J Neurointerv Surg* 2017;9(3):316–23. [PubMed: 26323793]
3. Mokin M, Snyder KV, Siddiqui AH, Levy EI, Hopkins LN. Recent Endovascular Stroke Trials and Their Impact on Stroke Systems of Care. *J Am Coll Cardiol* 2016;67(22):2645–55. [PubMed: 27256836]
4. Kunz WG, Hunink MG, Sommer WH, Beyer SE, Meinel FG, Dorn F, et al. Cost-Effectiveness of Endovascular Stroke Therapy: A Patient Subgroup Analysis From a US Healthcare Perspective. *Stroke* 2016;47(11):2797–804. [PubMed: 27758942]
5. Milne MS, Holodinsky JK, Hill MD, Nygren A, Qiu C, Goyal M, et al. Drip ‘n Ship Versus Mothership for Endovascular Treatment: Modeling the Best Transportation Options for Optimal Outcomes. *Stroke* 2017;48(3):791–4. [PubMed: 28100764]
6. Katz BS, Adeoye O, Sucharew H, Broderick JP, McMullan J, Khatri P, et al. Estimated Impact of Emergency Medical Service Triage of Stroke Patients on Comprehensive Stroke Centers: An Urban Population-Based Study. *Stroke* 2017;48(8):2164–70. [PubMed: 28701576]
7. Kesinger MR, Sequeira DJ, Buffalini S, Guyette FX. Comparing National Institutes of Health Stroke Scale among a stroke team and helicopter emergency medical service providers. *Stroke* 2015;46(2):575–8. [PubMed: 25538202]
8. Nazliel B, Starkman S, Liebeskind DS, Ovbiagele B, Kim D, Sanossian N, et al. A brief prehospital stroke severity scale identifies ischemic stroke patients harboring persisting large arterial occlusions. *Stroke* 2008;39(8):2264–7. [PubMed: 18556587]
9. Pérez de la Ossa N, Carrera D, Gorchs M, Querol M, Millán M, Gomis M, et al. Design and validation of a prehospital stroke scale to predict large arterial occlusion: the rapid arterial occlusion evaluation scale. *Stroke* 2014;45(1):87–91. [PubMed: 24281224]
10. Brandler ES, Sharma M, Sinert RH, Levine SR. Prehospital stroke scales in urban environments: a systematic review. *Neurology* 2014;82(24):2241–9. [PubMed: 24850487]
11. Studnek JR, Asimos A, Dodds J, Swanson D. Assessing the validity of the Cincinnati prehospital stroke scale and the medic prehospital assessment for code stroke in an urban emergency medical services agency. *Prehosp Emerg Care* 2013;17(3):348–53. [PubMed: 23495755]
12. Dozois A, Hampton L, Kingston CW, Lambert G, Porcelli TJ, Sorenson D, et al. PLUMBER Study (Prevalence of Large Vessel Occlusion Strokes in Mecklenburg County Emergency Response). *Stroke* 2017;48(12):3397–9. [PubMed: 29070716]
13. Bogle BM, Asimos AW, Rosamond WD. Regional Evaluation of the Severity-Based Stroke Triage Algorithm for Emergency Medical Services Using Discrete Event Simulation. *Stroke* 2017;48(10):2827–35. [PubMed: 28916666]
14. Asimos AW, Ward S, Brice JH, Rosamond WD, Goldstein LB, Studnek J. Out-of-hospital stroke screen accuracy in a state with an emergency medical services protocol for routing patients to acute stroke centers. *Ann Emerg Med* 2014;64(5):509–15. [PubMed: 24746847]
15. Saver JL, Fonarow GC, Smith EE, Reeves MJ, Grau-Sepulveda MV, Pan W, et al. Time to treatment with intravenous tissue plasminogen activator and outcome from acute ischemic stroke. *JAMA* 2013;309(23):2480–8. [PubMed: 23780461]
16. Barlinn J, Gerber J, Barlinn K, Pallesen LP, Siepmann T, Zerna C, et al. Acute endovascular treatment delivery to ischemic stroke patients transferred within a telestroke network: a retrospective observational study. *Int J Stroke* 2017;12(5):502–9. [PubMed: 27899742]

17. Ionita CC, Sharma J, Janicke DM, Levy EI, Siddiqui AH, Agrawal S, et al. Acute ischemic stroke and thrombolysis location: comparing telemedicine and stroke center treatment outcomes. *Hosp Pract* (1995). 2009;37(1):33–9.
18. Kodankandath TV, Wright P, Power PM, De Geronimo M, Libman RB, Kwiatkowski T, et al. Improving Transfer Times for Acute Ischemic Stroke Patients to a Comprehensive Stroke Center. *J Stroke Cerebrovasc Dis* 2017;26(1):192–5. [PubMed: 27743926]
19. Morris S, Hunter RM, Ramsay AI, Boaden R, McKeivitt C, Perry C, et al. Impact of centralising acute stroke services in English metropolitan areas on mortality and length of hospital stay: difference-in-differences analysis. *BMJ* 2014;349:g4757. [PubMed: 25098169]
20. Prabhakaran S, Ward E, John S, Lopes DK, Chen M, Temes RE, et al. Transfer delay is a major factor limiting the use of intra-arterial treatment in acute ischemic stroke. *Stroke* 2011;42(6):1626–30. [PubMed: 21527756]
21. Health NYSDo. Statewide Planning and Research Cooperative System (SPARCS) 2015 [Available from: <https://www.health.ny.gov/statistics/sparcs/>].
22. Staiger D, Stock JH. Instrumental Variables Regression with Weak Instruments. *Econometrica* 1997;65(3):557–86.
23. Neuman MD, Rosenbaum PR, Ludwig JM, Zubizarreta JR, Silber JH. Anesthesia technique, mortality, and length of stay after hip fracture surgery. *JAMA* 2014;311(24):2508–17. [PubMed: 25058085]
24. Tan HJ, Norton EC, Ye Z, Hafez KS, Gore JL, Miller DC. Long-term survival following partial vs radical nephrectomy among older patients with early-stage kidney cancer. *JAMA* 2012;307(15):1629–35. [PubMed: 22511691]
25. Xian Y, Holloway RG, Chan PS, Noyes K, Shah MN, Ting HH, et al. Association between stroke center hospitalization for acute ischemic stroke and mortality. *JAMA* 2011;305(4):373–80. [PubMed: 21266684]
26. Garabedian LF, Chu P, Toh S, Zaslavsky AM, Soumerai SB. Potential bias of instrumental variable analyses for observational comparative effectiveness research. *Ann Intern Med* 2014;161(2):131–8. [PubMed: 25023252]
27. Foster EM. Instrumental Variables for logistic regression: an illustration. *Soc Sci Res* 1997;26:287–504.
28. Sanossian N, Liebeskind DS, Eckstein M, Starkman S, Stratton S, Pratt FD, et al. Routing Ambulances to Designated Centers Increases Access to Stroke Center Care and Enrollment in Prehospital Research. *Stroke* 2015;46(10):2886–90. [PubMed: 26265130]
29. Prabhakaran S, O'Neill K, Stein-Spencer L, Walter J, Alberts MJ. Prehospital triage to primary stroke centers and rate of stroke thrombolysis. *JAMA Neurol* 2013;70(9):1126–32. [PubMed: 23817961]
30. 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. [PubMed: 21672403]
31. Mullen MT, Branas CC, Kasner SE, Wolff C, Williams JC, Albright KC, et al. Optimization modeling to maximize population access to comprehensive stroke centers. *Neurology* 2015;84(12):1196–205. [PubMed: 25740858]
32. Jayaraman MV, Iqbal A, Silver B, Siket MS, Amedee C, McTaggart RA, et al. Developing a statewide protocol to ensure patients with suspected emergent large vessel occlusion are directly triaged in the field to a comprehensive stroke center: how we did it. *J Neurointerv Surg* 2017;9(3):330–2. [PubMed: 26940315]
33. Southerland AM, Johnston KC, Molina CA, Selim M, Kamal N, Goyal M. Suspected Large Vessel Occlusion: Should Emergency Medical Services Transport to the Nearest Primary Stroke Center or Bypass to a Comprehensive Stroke Center With Endovascular Capabilities? *Stroke* 2016;47(7):1965–7. [PubMed: 26896433]
34. Zhao H, Coote S, Pesavento L, Churilov L, Dewey HM, Davis SM, et al. Large Vessel Occlusion Scales Increase Delivery to Endovascular Centers Without Excessive Harm From Misclassifications. *Stroke* 2017;48(3):568–73. [PubMed: 28232591]

35. Bekelis K, Marth NJ, Wong K, Zhou W, Birkmeyer JD, Skinner J. Primary Stroke Center Hospitalization for Elderly Patients With Stroke: Implications for Case Fatality and Travel Times. *JAMA Intern Med* 2016;176(9):1361–8. [PubMed: 27455403]
36. NeuroPoint Alliance. The National Neurosurgery Quality and Outcomes Database (N²QOD) 2015 [Available from: <http://www.neuropoint.org/NPAN2QOD.html>].

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

Table 1.

Patient characteristics

		All Patients		Patients transferred for stroke care		Patients not transferred for stroke care		P-Value
		N=128122		N=14450		N=113672		
		Mean	SD	Mean	SD	Mean	SD	
Age		70.38	14.80	66.14	15.14	70.92	14.67	<0.0001
		N	%	N	%	N	%	P-Value
Female gender		64323	50.21	6469	44.77	57854	50.90	<0.0001
Race	Caucasian	80702	63.08	9832	68.14	70870	62.43	<0.0001
	African-American	20781	16.24	1396	9.67	19385	17.08	<0.0001
	Hispanic	10387	8.12	634	4.39	9753	8.59	<0.0001
	Asian	3038	2.37	304	2.11	2734	2.41	0.024
	Other	13033	10.19	2264	15.69	10769	9.49	<0.0001
Insurance	Medicare	77796	60.82	7763	53.89	70033	61.70	<0.0001
	Medicaid	7674	6.00	977	6.78	6697	5.90	<0.0001
	Private	38648	30.21	5072	35.21	33576	29.58	<0.0001
	Uninsured	2384	1.86	307	2.13	2077	1.83	0.012
	Other	1416	1.11	285	1.98	1131	1.00	<0.0001
Transient Ischemic Attack		6591	5.14	431	2.98	6160	5.42	<0.0001
Coronary Artery Disease		44790	34.96	5504	38.09	39286	34.56	<0.0001
Chronic Obstructive Pulmonary Disease		19743	15.41	2309	15.98	17434	15.34	0.044
Congestive Heart Failure		25868	20.19	3094	21.41	22774	20.03	<0.0001
Diabetes Mellitus		43581	34.02	4414	30.55	39167	34.46	<0.0001
Coagulopathy		4563	3.56	638	4.42	3925	3.45	<0.0001
Chronic Renal Failure		19597	15.30	2058	14.24	17539	15.43	<0.0001
Hypertension		99187	77.42	10553	73.03	88634	77.97	<0.0001
Smoking		16972	13.25	2245	15.54	14727	12.96	<0.0001
Hypercholesterolemia		64235	50.14	7222	49.98	57013	50.16	0.689
Obesity		9685	7.56	1176	8.14	8509	7.49	0.005
Alcohol		5095	3.98	666	4.61	4429	3.90	<0.0001
Peripheral Vascular Disease		14258	11.13	1853	12.82	12405	10.91	<0.0001

SD: Standard Deviation

Table 2.
Multivariable models examining the association of transfer to an endovascular-capable center with outcomes

	Inpatient Mortality [¶]	Discharge to a facility [¶]	Length-of-stay [§]	P-value
	Adjusted Difference (95% CI)	Adjusted Difference (95% CI)	Adjusted difference (95% CI)	P-value
All patients				
Instrumental variable analysis *	4.4% (-0.1% to 9.0%)	-2.3% (-5.2% to 0.6%)	4.2 (-2.2 to 10.1)	0.546
Patients receiving IV-tPA				
Instrumental variable analysis *	3.5% (-1.4% to 8.4%)	-1.9% (-4.8% to 1.0%)	3.5 (-2.9 to 9.4)	0.432
Patient undergoing mechanical thrombectomy				
Instrumental variable analysis *	2.9% (-2.1% to 7.8%)	-2.2% (-4.6% to 1.3%)	3.9 (-2.5 to 9.9)	0.693

CI: confidence intervals

* The percentage of transferred stroke patients in each endovascular-capable hospital was used as an instrument

¶ Regressions based on probit models

§ Regressions based on linear models