Ischemic Stroke Transfer Patterns in the Northeast United States

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Background: Little is known about how hospitals are connected in the transfer of ischemic stroke (IS) patients. We aimed to describe differences in characteristics of transferred versus nontransferred patients and between transferring and receiving hospitals in the Northeastern United States, and to describe changes over time. *Methods:* We used Medicare claims data, and a subset linked with the Get with the Guidelines-Stroke registry from 2007 to 2011. Receiving hospitals were those with annual IS volume greater than or equal to 120 and greater than or equal to 15% received as transfers, and transferring hospitals were nonaccepting hospitals that transferred greater than or equal to 15% of their total (ED plus inpatient) IS patient discharges. A transferring-to-receiving hospital connection was identified if greater than or equal to 5 patients per year were shared. ArcGIS 10.3.1 was used for network visualization. *Results:* Among 177,270 admissions to 402 Northeast hospitals, 6906 (3.9%) patients were transferred. Transferred patients were younger with more severe strokes (78 versus 81 years, $P < .001$; National Institutes of Health Stroke Severity 7 versus 5, $P < .001$), and were as likely to receive tissue plasminogen activator as nontransferred ($P = .29$). From 2007 to 2011, there were more patients transferred (960 [3%] to 1777 [6%], $P < .001$), and more transferring hospitals (46 [12%] to 91 [24%], $P < .001$), and receiving hospitals (6 [2%] to 16 [4%], $P < .001$). Most transferring hospitals were exclusively connected to a single receiving hospital. *Conclusions:* From 2007 to 2011, hospitals in the United States Northeast became more connected in the care of IS patients, with increasing patient transfers and hospital connections. Yet most hospitals remained unconnected. Further characterization of this transfer network will be important for understanding and improving regional stroke systems of care.

Key Words: Stroke—patient transfer—delivery of healthcare—systems of care.

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Introduction

Prior studies have demonstrated substantial variation in stroke patient outcomes and in hospital performance in caring for ischemic stroke (IS) patients.[1-5] Some of the variation in patient outcomes is likely related to hospital-level variation in resource availability, such as the presence of stroke neurologists, dedicated stroke units or neurointensive care units, and availability of endovascular therapies.

Improved organization of stroke systems may decrease variation and improve patient outcomes, in part; this may occur through the presence of interconnected networks of hospitals. Such improved connections between hospitals may bring resources to patients at remote hospitals (eg, through telemedicine), or connect remote patients to a centralized resources (eg, through patient transfer). A 2010 Institute of Medicine policy agenda calls for more effective transfer of patients to hospitals of higher capability in order to improve patient outcomes,[6] while the American Stroke Association has advocated for improved organization of stroke systems of care—a key feature of which is the transfer of select AIS patients to centers of excellence for interventional care.[7] Yet how hospitals share in the care of patients with IS and are connected to each other has not been well-characterized.

To address this knowledge gap, our aim was to understand the complex network of connections between hospitals in the Northeast as determined by the transfer of IS patients between them. Understanding these patterns of care for transferred patients versus those who arrive at the hospital directly from the scene (ie, nontransferred) will inform future work in strengthening stroke systems of care in the region. Our objectives are threefold: (1) to describe differences in patient characteristics (between transferred versus nontransferred patients), (2) to describe differences in hospital characteristics (between transferring versus receiving hospitals), and (3) to describe the location and frequency of between-hospital connections as defined by interhospital patient transfers, present a visual representation of the established connections in the Northeast and to characterize the evolution of these connections over time.

Materials and Methods

Data Source and Population

We used Medicare enrollment, outpatient and inpatient claims data for states in the Northeast region (Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, Vermont) from 2007 to 2011. These data have been linked by probabilistic matching with data from the American Hospital Association's Get with the Guidelines (GWTG)-Stroke registry, which is a voluntary, hospital-based quality improvement registry collecting a range of clinical data on patients hospitalized for stroke.[8] The data linkage process is based on unique combinations of data fields (hospital identity code, admission and discharge dates, date of birth, and sex).[9] Approximately 70% of the registry's patients 65 years and older have been successfully linked, and the matched cohort is representative of the overall registry and national Medicare population.[10] This study was approved by our institution's IRB. RM has full access to the data and takes responsibility for its integrity and the data analysis.

Patients hospitalized for stroke were identified by discharge diagnosis ICD-9-CM codes 433.x1, 434.x1, and 436 or by primary diagnosis of IS in the GWTG-Stroke registry. All patients with discharge diagnosis codes for IS in the Medicare data were included. Among the GWTG-stroke registry identified patients, 96.1% were also identified using the Medicare claims diagnosis codes; all of these patients were included regardless of the primary discharge diagnosis code. Transferred patients were defined on the basis of data obtained from the Medicare claims as those with (1) an ED or inpatient billing claim from an initial hospital (sending hospital), (2) an inpatient billing claim from a second hospital (accepting hospital) on the same or consecutive date, and (3) discharge from the second hospital.[11,12]

Variables of Interest

Patient demographics were obtained from Medicare data and were available for all patients. Intravenous tissue plasminogen activator (tPA) receipt was determined using both Medicare data (based a billing code 9910 for the treatment) and the GWTG-Stroke registry. Past medical history variables, stroke severity (National Institutes of Health Stroke Severity [NIHSS] score), onset-to-arrival time, and tPA treatment times were present only from the GWTG-Stroke registry. Thus, these variables were only available for the subset of patients who were in the GWTG registry. For transferred patients, door-to-needle time for tPA delivery was calculated based on the arrival time at the hospital where the tPA was given.

Hospital characteristics (urban versus rural and teaching status) were drawn from the American Hospital Association 2008 database and was available for all hospitals. We identified hospitals with endovascular capabilities as those hospitals with at least 5 inpatient discharges that included at least 1 of the following thrombectomy procedure codes: 397.4, 397.5, and 397.6.[13] We identified hospitals with stroke center certification at the state level, by Det Norske Veritas Healthcare, or by Joint Commission using publicly available data for GWTG-Stroke hospitals.[14] We identified hospitals' Performance Achievement Award status annually by the publicly available GWTG source. Finally, among GWTG registry-participating hospitals, we examined each hospital's performance on 7 stroke care performance measures: intravenous tPA within 2 hours, early antithrombotics and deep vein thrombosis prophylaxis, and discharge prescription of

antithrombotics, anticoagulation for atrial fibrillation, statin medication, and smoking cessation counseling.[15] Each hospital was scored based on a composite measure of adherence that includes the proportion of care opportunities across all patients that were fulfilled,[15] and hospitals were categorized into quartiles based on scores.

Receiving hospital was defined as any hospital that received at least 15% of its annual IS volume as patient transfers, and had at least 120 IS discharges per year. We imposed a minimum patient volume threshold in order to ensure that receiving hospitals were those with both a larger absolute as well as proportional volume of patient transfers received. This was intended to ensure that receiving hospitals would be hospitals with a higher level of resources (eg, dedicated stroke units and endovascular capability). Each hospital was given a status as receiving or nonreceiving hospital for each year of the study period. For the overall characterization and summary map, any hospital that was given a receiving designation in at least 1 year of the study period was included as a receiving hospital.

A transferring hospital was defined as any hospital that was not a receiving hospital, and that transferred out at least 15% of its ED and inpatient IS volume, and had at least 5 IS discharges per year. A threshold of 5 discharges per year was chosen in order to limit the noise in our results. Each hospital was given a status as transferring or nontransferring for each year of the study period. For the overall characterization and summary map, any hospital that had transferring status in at least 1 year of the study period was included as a transferring hospital. A connection between a given pair of hospitals (or dyad) was identified if in any given calendar year at least 5 IS patients were transferred from a transferring to a receiving hospital. Therefore, if a transferring hospital did not transfer at least 5 IS patients to any one receiving hospital in a given year, it will be considered a transferring hospital, but will not be identified in any dyads of connected hospitals.

Statistical Analysis

We used descriptive statistics to characterize patients by transfer status, and to describe the population of hospitals by status as receiving hospital, transferring hospital, or neither. We also used descriptive statistics to characterize these transferring-receiving hospital dyadic connections, and to describe changes in the topology of the stroke transfer network map over time. Differences in these characteristics were compared using Pearson's chi-square for categorical row variables and Kruskal-Wallis tests for continuous variables.

All analyses were performed using SAS 9.4 (SAS Institute, Cary, NC). Two-tailed- P less than .05 was considered statistically significant. We used ArcGIS 10.3.1 (Esri, Redlands, CA) to generate a map of hospital connections for each year during the study period, as well as an overall summary map for the entire study period.

Results

There were 155,631 Medicare inpatient admissions identified in the study period. Of these 664 patients were excluded because their admission date was January 1, 2007 and, therefore, would not have previous admission data to identify a transfer. Of the remaining 154, 967 Medicare patients in our sample, 55.3% had a linkage to a GWTG-Stroke registry admission (Fig 1). Linked patients were similar to nonlinked patients with respect to age

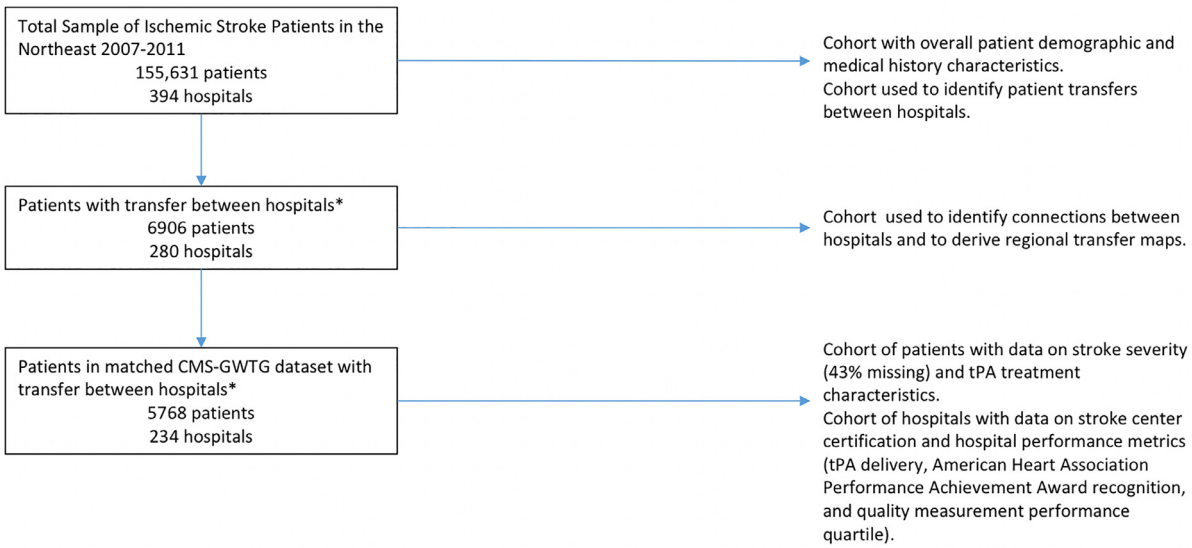

Figure 1. *Data derivation, *Patient transfers identified using medicare data, based upon consecutive claims from an initial sending hospital and a second accepting hospital.*

(median [IQR] in years, 81 [74-87] versus 81 [74-87]), female sex (59% versus 57%), and white race (85% versus 81%). Patient-level data on stroke severity was available for most transferred patients in the GWTG-Stroke registry (n = 3262, 57%), defined as the earliest recorded NIHSS score from either a sending hospital (n = 392, 12%) or an accepting hospital (n = 2870, 88%).

There were 402 hospitals in the Northeast during the study period. Eight hospitals were excluded as they had no IS patient transfers or admissions during the study period. There were 17 hospitals (4.2%) meeting the definition for receiving hospital, and 136 (33.8%) for transferring hospital during at least 1 year of the study period. Two hundred forty-one hospitals (60.0%) did not meet the definition for transferring hospital or for receiving hospital during any year of the study period. Sixteen (94%) of the receiving hospitals and 48 (35%) of the transferring hospitals were GWTG-Stroke participants with patient-level data on patient stroke severity (NIHSS) and stroke care performance metrics including tPA delivery in at least 1 year of the study period.

Transferred Versus Nontransferred Patients

Of the 154,967 IS patients, 6906 (4.5%) were transferred between hospitals. The number of patients transferred increased from 2007 to 2011 (960 [3.1%] to 1777 [5.6%], *P* for trend <.001). Relative nontransferred patients, transferred patients were slightly younger, more often male, and more often white (Table 1).

When transferred, patients more frequently arrived at hospitals that were larger, academic, with higher annual stroke volume, and with endovascular capabilities, and less frequently at rural hospitals (Table 1). Among the subset of patients with GWTG-Stroke data available (n = 85,992, 55.3%), relative to nontransferred patients, transferred patients were also treated at hospitals with higher stroke severity, and better performance on tPA delivery metrics and quality measure performance (Table 1).

Among the subset of patients with GWTG-Stroke data, transferred patients had more severe strokes than nontransferred patients as measured by NIHSS (median of 7 versus 5 on first recording, $P < .001$), and median NIHSS among transferred patients increased between the transferring hospital and the destination hospital (median [IQR] 6 [2.5-15] versus 7 [3-16]). Transferred patients were as likely to be treated with tPA relative to nontransferred patients (5.5% versus 5.2%, $P = .29$), and among transferred patients, most (66%) tPA-treated patients received tPA at the second, destination hospital (1.9% at the first hospital of presentation versus 3.7% at the destination hospital, $P < .001$). Hospital performance on tPA delivery was better for transferred patients treated at the receiving hospital than for transferred patients treated at the transferring hospital (median DTN 59 at the receiving hospital, versus 79 for those treated at the transferring hospital, $P = .01$; and DTN within 60 minutes was achieved among 52.8% of tPA-treated transferred patients at the receiving hospital versus 29.6% of transferred patients who were treated at the transferring hospital, $P < .001$).

Hospital Characteristics

Overall, we identified 153 hospitals (38%) as either transferring or receiving hospitals in the Northeast (136 [88.9%] transferring, and 17 [11.1%] receiving). Hospitals that did not meet the definition for transferring or receiving hospital were more similar to transferring hospitals (Supplementary Table I). Receiving hospitals were more frequently academic, and less frequently rural, and had higher annual stroke volume (Table 2). Among GWTG-Stroke participating hospitals (transferring hospitals: n = 48 [35%], receiving hospitals: n = 16 [94%]), receiving hospitals had higher patient stroke severity, and better performance on tPA delivery metrics (Table 3).

The Northeast IS Transfer Network Map

Figure 2 presents the summary map for the IS transfer network in the Northeast from 2007 to 2011. There were 88 network ties between 93 unique transferring and receiving hospitals during the study period. Fifty-seven transferring hospitals had 0 connections because they did not transfer at least 5 patients to a given receiving hospital in any given calendar year. All 17 receiving hospitals were involved in at least 1 connection.

The median driving distance between a connected transferring and receiving hospital was 37.0 miles (IQR 23.2-55.2), and the median driving time was 49.5 minutes (IQR 31.0-69.0). Over the full study period, the median number of patients transferred between the connected hospitals in the 88 days was 20.5 (IQR 15.0-34.0). Eleven connections crossed hospital referral region boundaries (13.4%), which accounted for 10.3% of transferred patients (n = 232).

Most (91.1%) of the 79 transferring hospitals with a dyadic connection to a receiving hospital were connected to a single receiving hospital. Of the 7 sending hospitals connected to more than 1 receiving hospital, 6 were connected to 2 different hospitals, and 1 was connected to 4. Four of these 7 hospitals had a preferred receiving hospital to which they sent at least two thirds of their transferred patients.

Changes in the IS Transfer Network Over Time

The Appendix presents the IS transfer network map for each year in the study period (2007-2011), and Figure 3 presents the maps for 2007 and 2011 for side-by-side comparison. The number of hospitals meeting definitions for transferring and receiving hospitals increased from 2007 to 2011 (transferring hospitals: 59 [14.7%] to 104 [25.9%]

Table 1. *Patient characteristics*

	All patients (n = 154,967)	Nontransferred patients (n = 148,061)	Transferred patients (n = 6906)	*P* value
Demographics				
Age, median (IQR)	81 (73-86)	81 (73-87)	78 (71-84)	<.001
Female gender, n (%)	78,060 (58.1)	74,616 (58.4)	3444 (52.5)	<.001
Race/ethnicity, n (%)				<.001
Hispanic	3057 (2.5)	2973 (2.6)	84 (1.3)	
Black	12,941 (10.5)	12,625 (10.8)	316 (5.0)	
Asian	1667 (1.4)	1620 (1.4)	47 (.7)	
White	102,799 (83.5)	97,037 (83.2)	5742 (90.4)	
Other/unknown	2580 (2.1)	2420 (2.1)	160 (2.5)	
Past medical history				
Atrial fibrillation/flutter, n (%)	23,096 (28.0)	21,355 (27.7)	1741 (32.8)	<.001
Prosthetic heart valve, n (%)	1291 (1.6)	1176 (1.5)	115 (2.2)	<.001
Coronary artery disease or prior myocardial infarction, n (%)	25,576 (31.0)	23,835 (30.9)	1741 (32.8)	.004
Carotid stenosis, n (%)	3524 (4.3)	3196 (4.2)	328 (6.2)	<.001
Diabetes mellitus, n (%)	24,207 (29.4)	22,644 (29.4)	1563 (29.4)	.91
Peripheral vascular disease, n (%)	3777 (4.6)	3474 (4.5)	303 (5.7)	<.001
Hypertension, n (%)	66,174 (80.3)	61,911 (80.3)	4263 (80.3)	.996
Heart failure, n (%)	7641 (9.3)	7134 (9.3)	507 (9.6)	.47
Smoking, n (%)	6187 (7.5)	5688 (7.4)	499 (9.4)	<.001
Hyperlipidemia, n (%)	35,518 (43.1)	32,943 (42.7)	2575 (48.5)	<.001
Prior stroke/TIA, n (%)	25,709 (31.2)	24,259 (31.5)	1450 (27.3)	<.001
Arrival details				
Onset-to-first hospital arrival time,*,† median (IQR)	164 (65-475)	165 (65-475)	144 (60-401)	.074
NIHSS score as first recorded,* median (IQR)	5 (2-13)	5 (2-12)	7 (3-16)	<.001
Hospital characteristics ‡				
Presentation to rural hospital, n (%)	11,455 (7.4)	11,055 (7.5)	400 (5.8)	<.001
Presentation to teaching hospital, n (%)	98,925 (64.3)	92,584 (63.0)	6341 (92.2)	<.001
Presentation to stroke center hospital, n (%)				<.001
State certification	46,278 (59.3)	43,930 (60.4)	2348 (44.9)	
DNV	2810 (3.6)	2458 (3.4)	352 (6.7)	
TJC	25,914 (33.2)	23,827 (32.8)	2087 (39.9)	
No certification	2987 (3.8)	2546 (3.5)	441 (8.4)	
Missing	5976 (7.1)	5834 (7.4)	142 (2.6)	
Median annual stroke volume at hospital of presentation in 2011 (IQR)	126 (73-207)	125 (73-206)	211 (182-329)	<.001
Endovascular capabilities, n (%)	23,053 (14.9)	19,733 (13.3)	3320 (48.1)	<.001
Mean hospital-average NIHSS at hospital of presentation (SD)	8.2 (1.8)	8.1 (1.8)	8.6 (1.5)	<.001
Median rate of tPA receipt at hospital of presentation,*,§ % (IQR)	82.8 (70-93.8)	82.6 (67.6-93.8)	85.6 (77.4-95.6)	<.001
Mean hospital-average DTN time at hospital of presentation* (SD)	81.3 (16.1)	81.3 (16.1)	78.9 (13.3)	<.001
Hospital rate of DTN within 60 minutes, median (IQR)	25.8 (17.7-37.2)	25.5 (17.4-36.4)	30.4 (22.2-45.5)	<.001
Presentation to a hospital receiving American Heart Association Performance Achievement Award, n (%)				<.001
Gold or gold+ & TS honor roll	37,758 (51.3)	33,902 (49.6)	3856 (73.6)	
Gold or gold+ without TS Honor Roll	28,860 (39.2)	27,688 (40.5)	1172 (22.4)	
All Others	6942 (9.4)	6732 (9.9)	210 (4.0)	
Missing	10,405 (12.4)	10,273 (13.1)	132 (2.5)	
Hospital of presentation quality measure performance quartile‖				<.001
Highest	22,976 (27.4)	20,406 (26.0)	2570 (47.9)	

(*Continued*)

Table 1 (*Continued*)

	All patients (n = 154,967)	Nontransferred patients (n = 148,061)	Transferred patients (n = 6906)	*P* value
High	25,914 (30.0)	23,206 (29.5)	1988 (37.0)	
Low	23,802 (28.4)	23,186 (29.5)	616 (11.5)	
Lowest	11,993 (14.3)	11,797 (15.0)	196 (3.7)	

Abbreviations: EMS: emergency medical services; IQR: interquartile range; NIHSS: National Institute of Health Stroke Scale; PCI: percutaneous coronary intervention; TIA: transient ischemic attack.

*Only reported for the subset of patients in the GWTG registry.

†For transferred patients, onset-to-arrival time is reported for initial hospital presentation.

‡For transferred patients, hospital characteristics describe the final accepting hospital characteristics.

§The proportion of tPA-eligible patients arriving within 2 hours of last-known-well, and treated within 3 hours.

‖Based on 7 stroke care performance measures (intravenous tPA within 2 hours, early antithrombotics and deep vein thrombosis prophylaxis, and discharge prescription of antithrombotics, anticoagulation for atrial fibrillation, statin medication, and smoking cessation counseling).[15]

$P < .001$; receiving hospitals also increased from 8 [2.0%] to 16 [4.0%], $P < .001$).

The number of ties in the hospital network (ie, connections involving the transfer of 5 or more patients between 2 hospitals) in the Northeast increased from 17 in 2007 to 55 in 2011, while over the same time period, the median number of patients transferred across those ties did not increase (9 [IQR 6-9] versus 7 [IQR 5-11] respectively, $P = .08$). The network topology evolved over the study period as network edges spanning greater distance and travel time appeared. This was evidenced by a trend toward increased driving distance in 2011 compared to 2007 (median [IQR] 35.0 [22.9-52.6] versus 27.3 miles [14.8-39.9], $P = .13$) and travel times (median [IQR] 45.0 [30.0-65.0] versus 34.0 minutes [28.0-50.0], $P = .13$). Some hospitals that met the definitions for transferring and receiving hospitals did not contribute any edges to the network of hospitals, as they had fewer than 5 transfers to or from any other hospital in any year.

Discussion

There have been many calls for development and improvement of stroke systems of care,[7,16-19] as well as descriptions of processes implemented to improve stroke systems.[20-23] To our knowledge, ours is the first topological description and spatial analysis of stroke systems of care in the United States. We found that an increasing number of transferring hospitals, receiving hospitals, and pairwise transfer relationships developed in the Northeast from 2007 to 2011. This reflects an increased number of transferred patients during the same time period, suggesting strengthening of relationships among hospitals. This also reflects an increased concentration of IS patients in receiving hospitals during the study period. Given that transferred patients tend to have more severe strokes, and the critical influence of stroke severity in long-term prognosis,[24] this redistribution of patients may have a mortality-concentrating effect with important implications on risk-adjustment procedures for measures of performance, outcomes, and mortality particularly at accepting hospitals.

Our current work reinforces prior observations from Canada,[25] from a Michigan stroke registry,[26] and from a single-institution study[27] that found that transferred patients were generally younger than nontransferred patients, and with more severe strokes as measured by higher NIHSS scores. We also found significant differences in comorbidities, with greater morbidity among transferred patients. This is similar to previous work that has also demonstrated that patients with more severe strokes and poststroke complications tend to concentrate at more advanced stroke centers.[26,27] Surprisingly, in contrast to a single institution report that most tPA-treated patients were treated prior to transfer,[27] we found that two thirds of tPA-treated transfer patients received their tPA at the receiving hospital *after transfer*. This may be partially explained by varying levels of decision-support among some transferring hospitals relative to others, such as connections to a receiving hospital via telestroke.[28]

Effective transfer of IS patients between hospitals is a critically important component of high-functioning stroke systems of care. This includes ensuring that appropriate patients are transferred, that they are transferred to centers with the level of resources required for their care, and that transfers take place efficiently. Consistent with our expectations, we found that receiving hospitals were generally larger, academic centers with endovascular capabilities and higher annual stroke volumes, and had better performance on tPA delivery metrics and quality measure performance. We also found that the vast majority of sending hospitals transferred patients to a single receiving hospital during the study period; this may reflect corporate or contractual relationships such as shared ownership, personal relationships derived from prior training environments, or telestroke-based relationships. Relationships that develop between hospitals during the transfer process may support mechanisms for communication of

Table 2. *Characteristics of hospitals classified as transferring or receiving*

	All transferring and receiving hospitals (n = 153)	Receiving hospitals (n = 17)	Transferring hospitals (n = 136)	*P* value
Rural location, n (%)	73 (48.3)	1 (5.9)	72 (53.7)	<.001
Teaching hospital, n (%)	43 (28.5)	17 (100.0)	26 (19.4)	<.001
Stroke center hospital,* n (%)				<.001
State	43 (76.8)	6 (37.5)	37 (92.5)	
DNV	0 (.0)	0 (0.0)	0 (0.0)	
TJC	11 (19.6)	9 (56.3)	2 (5.0)	
No certification	2 (3.6)	1 (6.3)	1 (2.5)	
Missing	8 (12.5)	0 (0.0)	8 (16.7)	
Median annual stroke volume, 2011 (IQR)	25 (11-57)	228 (194-329)	22 (10-41)	<.001
Endovascular capabilities, n (%)	10 (6.5)	10 (58.8)	0 (0.0)	<.001
Mean hospital-average NIHSS,* mean (SD)	7.3 (2.4)	8.9 (1.3)	6.8 (2.5)	<.001
Rate of tPA receipt among eligible patients,† median (IQR)	73.2 (8.8-85.5)	84.7 (77.1-91.0)	36.4 (0.0-80.0)	<.001
Mean hospital-average DTN time in minutes,* mean (SD)	83.4 (17.3)	77.5 (10.6)	86.7 (19.4)	.08
Proportion of patients receiving DTN within guideline recommended 60-minute window,*,‡ median (IQR)	25.0 (7.7-42.9)	30.4 (21.2-44.0)	20.0 (0.0-35.3)	.14
Hospitals receiving American Heart Association Performance Achievement Award,* n (%)				
Gold or gold+ & TS Honor roll	19 (45.2)	12 (75.0)	7 (26.9)	.01
Gold or gold+ without TS honor roll	15 (35.7)	3 (18.8)	12 (46.2)	
All others	8 (19.1)	1 (6.3)	7 (26.9)	
Missing	22 (34.4)	0 (0.0)	22 (45.8)	
Quality measure performance quartile,*,§ n (%)				.002
Highest	16 (25.0)	6 (37.5)	10 (20.8)	
High	15 (23.4)	8 (50.0)	7 (14.6)	
Low	15 (23.4)	2 (12.5)	13 (27.1)	
Lowest	18 (28.1)	0 (0.0)	18 (37.5)	

Abbreviations: DTN, door-to-needle time; IQR, interquartile range; NIHSS, National Institutes of Health Stroke Scale.

*Only reported for the subset of hospitals in the GWTG registry.

†Proportion of patients arriving within 2 hours of last-known-well and treated within 3 hours.

‡The denominator for this variable includes *all* patients eligible for t-PA, including those not treated.

§based on 7 stroke care performance measures (iv tPA < 2 hours, early antithrombotics, DVT prophylaxis, antithrombotics at discharge, lipid-lowering medication, and smoking cessation).

Table 3. *Patient arrival and treatment characteristics*

	Nontransferred patients (n = 148061)	Transferred patients (n = 6906)			
		First hospital	*P* value[†]	Second hospital	*P* value[‡]
Onset to arrival time in minutes, median (IQR)	165 (65-475)	144 (60-401)	.07	342 (240-655)	<.001
Onset to arrival time among tPA-treated patients in minutes, median (IQR)	58 (40-85)	54 (40-85)	.88	192.5 (99-265.5)	<.001
NIHSS score, median (IQR)	5 (2-12)	6 (2.5-15)	<.001	7 (3-16)	<.001
tPA treatment, n (%)	7693 (5.2)	130 (1.9)	<.001	256 (3.7)	<.001
Door-to-needle time in minutes,* median (IQR)	75 (58-96)	79 (57-99)	.71	59 (41-82)	<.001
Door-to-needle time within 60 minutes,* n (%)	1377 (29.6)	21 (29.6)	.9995	28 (52.8)	<.001

Abbreviation: tPA, tissue plasminogen activator.
* Among patients treated with tPA.
[†]For comparison between front-door patients and transferred patients at first hospital.
[‡]For comparison between front-door patients and transferred patients at second.

best practices which could influence the quality of care at each site, essentially functioning as a vector for the "transmission of quality" between hospitals. Thus, these identified connections between hospitals may help explain hospital-level variation and differences in patient outcomes.

Our study has several potential limitations. Our inability to examine this question in more recent years (since 2011) is a limitation; the network map of 2011 may have significantly evolved in the last 7 years. Furthermore, findings from the Northeast region may not be generalizable to other regions of the country with less density or other differences in system characteristics. Some of the variables we examined were only available from the subset of patients treated at hospitals participating in the GWTG-Stroke registry which tend to be larger and more resourced hospitals, therefore, some findings may not be generalizable to nonregistry hospitals. Lastly, our definition of transferring and receiving hospitals although derived from the data are still somewhat arbitrary. It is reassuring that our definition of a receiving hospital has face validity as it identified major academic centers in the Northeast, however only 10 of the 17 centers had endovascular capabilities during the study period. Future work with a larger hospital sample size will allow us to test alternative definitions of transferring and receiving sites as we expand this method to all U.S. hospitals.

Further investigation is needed to understand the implications of these interhospital connections, to determine whether these connections serve as mechanisms for knowledge transmission, and whether transferring hospitals are influenced by the receiving hospitals to which they are connected. By our definitions, the majority of hospitals remained unconnected in the Northeast during our study period. If, in fact, interhospital connections are meaningful routes for the spread of best practices, this may represent a missed opportunity. Future research is also needed to explore the association of network characteristics with patient outcomes. Finally, though our results are from the preendovascular era, it remains the case that relatively few hospitals have endovascular capabilities. Thus stroke systems will inevitably require reorganization in order to increase access and reduce treatment times for thrombectomy-eligible patients. Changes are likely to occur both in prehospital triage and destination decisions, as well as in the interhospital transfer process, leading to increased transfer of patients to hospitals with endovascular capabilities. Better understanding the network composition and how these changes occur will be an important aspect of our future research work, and a critical component to improving stroke systems.

In conclusion, from 2007 to 2011, hospitals in the Northeast became increasingly connected in the care of IS patients. Future work should characterize how systems of care have evolved in response to the more recent evidence for benefit of endovascular intervention, and whether

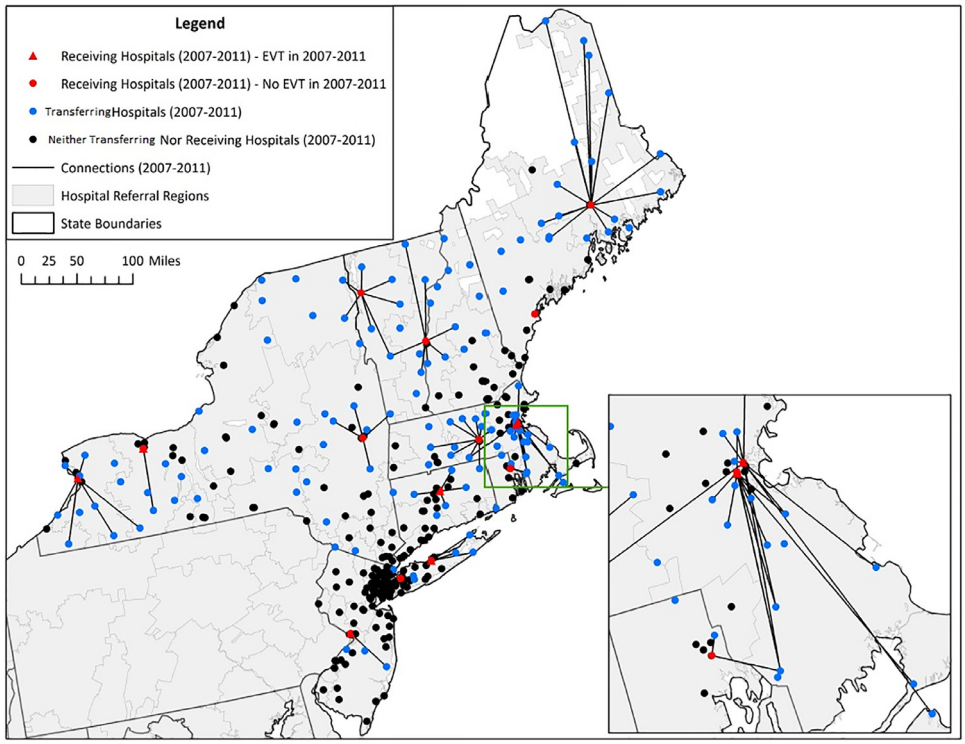

Figure 2. *Northeast ischemic stroke transfer network, cumulative topography, 2007-2011. EVT, endovascular thrombectomy.*

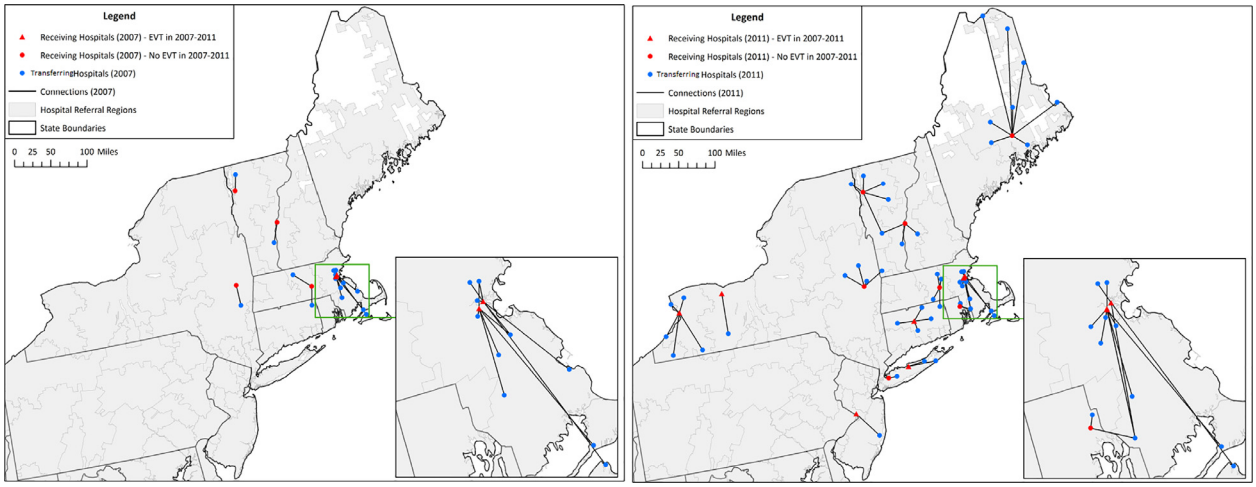

Figure 3. *Northeast ischemic stroke transfer network map, 2007 versus 2011.*

network-level characteristics help explain hospital-level variation in patient outcomes.

Disclosures

KSZ, JPO, AH, MJR, CAC, MC, RM, JPM, and JNG have no conflicts to disclose. LHS reports being the principal investigator of an investigator-initiated study of extended-window intravenous thrombolysis funded by the National Institutes of Neurological Disorders and Stroke (clinicaltrials.gov/show/NCT01282242) for which Genentech provided alteplase free of charge to Massachusetts General Hospital as well as supplemental perpatient payments to participating sites; serving as chair of the AHA/ASA GWTG stroke clinical work group and Target: Stroke initiative; service 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, 4 trial), Penumbra (data and safety monitoring committee, Separator 3D trial) and Medtronic (Victory AF, REACT AF, and Stroke AF trials).

Supplementary Materials

Supplementary data to this article can be found online at doi:10.1016/j.jstrokecerebrovasdis.2018.09.048.

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