Regional Learning Collaboratives Produce Rapid and Sustainable Improvements in Stroke Thrombolysis Times

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Background—Reduction in door-to-needle (DTN) times in patients with acute ischemic stroke treated with tissue-type plasminogen activator is associated with improved outcomes. We hypothesized that a learning collaborative would rapidly reduce DTN times at Chicago’s primary stroke centers.

Methods and Results—We analyzed data from all adult patients with out-of-hospital ischemic stroke hospitalized between January 1, 2010 and March 31, 2015 and who received tissue-type plasminogen activator in the emergency department at 15 primary stroke centers in Chicago and 15 primary stroke centers in St. Louis. We implemented a structured learning collaborative in Chicago in quarter 1 of 2013 that included (1) a quality improvement leader, (2) stroke content expert, (3) multidisciplinary teams from each site, (4) a targeted goal for the program (DTN time <60 minutes in >/=50% of patients treated with tissue-type plasminogen activator), and (5) face-to-face meetings with on-site visits. We used interrupted time-series analysis to compare the impact of the learning collaborative on DTN times in Chicago pre- and post implementation and also concurrently versus St. Louis. We prespecified adjustment for mode of arrival, emergency medical services prenotification, and onset-to-arrival times. P values less than 0.05 were considered significant. In adjusted analysis, the reduction in DTN time within 1 quarter of implementation was 15.5 minutes (P=0.046) at Chicago sites versus 1.17 minutes at St. Louis sites (P=0.601).

Conclusions—Using a learning collaborative model at Chicago’s 15 primary stroke centers, we observed major reductions in DTN times within 1 quarter of implementation. Regional collaboration and best practices sharing should be a model for rapid and sustainable system-wide quality improvement. (Circ Cardiovasc Qual Outcomes. 2016;9:585-592. DOI: 10.1161/CIRCOUTCOMES.116.003222.)

Key Words: Chicago ■ emergency medical services ■ quality improvement ■ stroke ■ thrombolysis

Stroke affects nearly 800,000 Americans annually and is a leading cause of adult disability in the United States. Designated stroke centers provide high levels of expertise and organization to improve process of care, deliver time-sensitive treatments efficiently, and reduce stroke-related mortality. In addition, adoption of quality improvement programs such as the American Heart Association/American Stroke Association (AHA/ASA) Get With the Guidelines-Stroke Program is associated with performance improvement in many other aspects of hospital-based stroke care.

The goal of early stroke treatment is to restore the blood flow as soon as possible and to reduce the damage and long-term disability. The time-dependent effect of tissue-type plasminogen activator (tPA) treatment on outcomes is well established. In patients with acute ischemic stroke eligible for tPA, every 15 minutes saved from symptom onset to initiation of tPA is associated with a 4% relative increase in good outcomes. Guidelines have established a goal door-to-needle (DTN) time of <60 minutes (class 1, level of evidence A).

On the basis of the Brain Attack Coalition guidelines important time benchmarks from patient with stroke arrival include (1) evaluation by emergency department (ED) physician in <10 minutes, (2) evaluation by stroke neurologist in <15 minutes, (3) rapid acquisition of computed tomography (CT) brain imaging in <25 minutes, (4) interpretation of brain imaging in <45 minutes, and (5) mixing and administration of tPA in <60 minutes of arrival or DTN time. Delays and errors can occur in each step of the process with considerable practice variability. Indeed, before the AHA/ASA’s Target Stroke Initiative, few US hospitals were achieving these goals.

Learning collaboratives (LCs) coalesce experts and care providers from multiple disciplines across different organizations to rapidly implement interventions. Although studied in other conditions, such as trauma in the ED, few have adopted this model in stroke quality improvement. We sought to evaluate the impact of a regional LC among 15 primary stroke centers (PSCs) in Chicago on reducing DTN times for stroke thrombolysis. We hypothesized that rapid and
WHAT IS KNOWN

• There is a time-dependent benefit for intravenous tissue-type plasminogen activator in patients with ischemic stroke, such that earlier treatment leads to better functional outcomes.
• Previous hospital-based efforts to reduce door-to-needle times for tissue-type plasminogen activator have been implemented in quality improvement initiatives, such as Target: Stroke.
• Learning collaboratives coalesce experts and care providers from multiple disciplines across different organizations to rapidly implement interventions to improve quality but have had limited application in the setting of acute stroke treatment.

WHAT THE STUDY ADDS

• We demonstrated the use of implementing a learning collaborative for reducing door-to-needle times across 15 Chicago hospitals.
• Compared with concurrent controls from St. Louis, we observed a 15-minute improvement within 1 quarter of implementation that was sustained over the subsequent 2 years.

Methods

There are nearly 3 million residents in Chicago (45% white, 33% black, and 29% Hispanic; http://www.census.gov/; accessed July 15, 2015). The Chicago Fire Department is the sole public emergency medical services (EMS) provider for the emergent transportation of patients with stroke. In 2009, Illinois passed a law permitting regional preferential transportation of suspected stroke patients to the nearest PSC. Chicago implemented a stroke triage policy in March 2011. We previously published on the impact of this policy on tPA treatment rates at Chicago PSCs.20

During the study period, 15 PSCs within city limits received suspected stroke patients by EMS (Figure I in the Data Supplement). All centers use the (GWTG-S) Get With The Guidelines-Stroke registry for quality improvement and aggregate regional data reporting and analysis. Each hospital expressed agreement with the AHA/ASA to share data and report results in aggregate form. We required the following data to be entered in the GWTG-S database for analysis: demographics (age, sex, race, and ethnicity), medical history (hypertension, diabetes mellitus, prior stroke, hyperlipidemia, and atrial fibrillation/flutter), mode of hospital arrival, EMS prenotification, times of symptom onset, CT imaging completed, and thrombolytic administration, initial stroke severity using the NIHSS (National Institutes of Health Stroke Scale), complications of thrombolytic therapy, and discharge outcomes. All data were entered by local site coordinators without central adjudication, interpretation, or review. All participating institutions were required to comply with local regulatory and privacy guidelines and, if required, to secure institutional review board approval. A GWTG-S superuser account was created to monitor and aggregate data in the region and was managed by the AHA/ASA.

The QUESTS (Quality Enhancement for Speedy Thrombolysis in Stroke) initiative aimed to improve DTN times at Chicago’s PSCs. It began in December 2012 and spanned 1 year. An LC model was adopted that included 5 required components: (1) a quality improvement leader (K.O.); (2) stroke content expert (S.P.); (3) multidisciplinary teams from each site, including stroke program coordinators, nurses, pharmacists, radiology technologists, and physicians from Neurology and Emergency Medicine; (4) a targeted goal for the program (DTN time ≤60 minutes in >50% of patients treated with tPA); and (5) face-to-face collaboration with on-site visits to each PSC and quarterly learning sessions with data sharing and experiential learning. Each participating site received a 5000 US Dollar incentive to participate in the initiative. Sites achieving the AHA’s Target Stroke Honor Roll during the funded year were awarded an additional 1500 US Dollar. The Target Stroke award required hospitals to achieve DTN time within 60 minutes or less in 50% of their eligible patients and a minimum of 6 cases.

The kick-off meeting was held on December 7, 2012 at the Chicago AHA office and was attended by representatives from each of the 15 PSCs. The meeting focused on the background data from the Chicago region, Target Stroke and other best practices, and the QUESTS initiative. From January 2013 and March 2013, in-person site visits to each PSC were conducted by the content expert and quality improvement leader. During each site visit, core stroke team members including coordinators, nurses, technologists, and EM and Neurology physicians were required to be present. A baseline survey was conducted, which evaluated practices associated with stroke thrombolysis (Figure II in the Data Supplement). On basis of these on-site evaluations and surveys, strategies and solutions for implementation were generated and proposed at each PSC. During the action periods that occurred between each learning session, stroke protocol leaders were asked to implement these strategies and monitor for DTN times as part of routine monthly quality improvement activities at each PSC. In addition, aggregate data reports were shared via e-mail and during monthly regional conference calls. Quarterly learning sessions were conducted in March, June, and September of 2013. The second and third sessions focused on unique best practices developed at participating institutions, including direct-to-CT protocols, a structured guide to informed consent, pharmacy procedure for premixing and administering tPA, and a template for providing team-based feedback. A final webinar was held on December 2, 2013 with invited speakers from Washington University Barnes Jewish Hospital discussing their lean-based approach to DTN process improvement.21 At the completion of the 1-year program, a follow-up survey of best practices was completed by each site.

We included patients admitted between January 1, 2010 and March 31, 2015 with ischemic stroke diagnosis and who received tPA in the ED; we excluded in-hospital stroke patients. We obtained aggregate quarterly data from 15 PSCs from St. Louis, MO, as concurrent control sites for comparison to our intervention sites. A stepped-wedge implementation was used such that each PSC in Chicago began implementing selected best practices in quarter 1 of 2013 after the site visit and the development of an individualized site action plan.

For the interrupted time-series analysis, we used segmented linear regression, which divides a time series into pre- and postimplementation periods. Because the intervention was implemented in Q1 2013, we chose Q2 2013 as the intersection between 2 time periods. The aggregate median DTN across 15 PSCs participating in QUESTS was computed for each quarter (Yt, where t=1–21 quarters). Segmented regression analysis was used to model the interrupted time-series data to estimate the change in level and trend with 1 change point. A change in level between pre- and postimplementation periods indicates a step-change, and a change in slope indicates a change in trend. The regression model used is written as follows:

\[ Y_t = \beta_0 + \beta_1 \times \text{time}_t + \beta_2 \times \text{implementation}_t + \beta_3 \times \text{time after implementation}_t + \epsilon_t \]

\( \beta_0 \) estimates the baseline level of the median DTN at the beginning of the time series. \( \beta_1 \) estimates the preimplementation trend where time is a continuous variable, indicating the time in quarters at time 0 from the start of the study period. \( \beta_2 \) estimates the change in level postimplementation where implementation=0 before the
implementation, and implementation = 1 after the implementation. \( \beta_1 \) estimates the change in postimplementation trend where time after implementation is a continuous variable indicating the number of quarters after the start of the implementation and is coded zero before the implementation. \( \epsilon \) includes random error and autocorrelation. We included a term in the regression model for the lagged residuals to correct for autocorrelation effects. Prespecified adjustment for mode of arrival, EMS prenotification, and onset to arrival time was performed. The same unadjusted and adjusted analyses were performed in concurrent control sites in St. Louis. Combined analyses were performed to compare intervention and control sites between pre- and post implementation. All \( P \) values were 2-sided and values less than 0.05 were considered significant. All analyses were performed using SAS 9.4 (Cary, NC).

Results

During the study period, there were a total of 10314 acute ischemic stroke admissions to the 15 PSCs in Chicago and 15261 acute ischemic stroke admissions to the 15 PSCs in St. Louis (Table 1). Overall in Chicago, 766 (7.8%) received intravenous tPA in the ED (8.5% postintervention versus 7.1% preintervention; \( P = 0.009 \)) compared with 10.7% in St. Louis (11.8% postintervention versus 9.8% preintervention; \( P < 0.001 \)). Patient characteristics of the intervention and control cohorts are presented in Table 1. Among those who received tPA in the ED in Chicago (Table 2), pre- and postimplementation groups were similar by demographics and risk factors except for a decrease in the frequency of EMS mode of arrival in the postimplementation period. In the subset in whom NIHSS score was recorded, there was no difference in NIHSS scores pre- and post implementation (\( P = 0.092 \)).

At intervention sites, compared with preimplementation, DTN and onset to treatment times were lower in the postimplementation period (DTN: 82 minutes versus 58 minutes, \( P < 0.001 \); onset to treatment: 151 minutes versus 131 minutes, \( P < 0.001 \)). The proportion of DTN times <60 minutes was also higher post implementation (59.1% versus 21.1%, \( P < 0.001 \)). No change in door-to-CT times were noted (16 minutes versus 18 minutes, \( P = 0.723 \)). Rate of symptomatic hemorrhage were similar pre- and post implementation (3.3% versus 3.0%, \( P = 0.989 \)), whereas the proportion of patients discharged home increased from 30.9% to 39.5% (\( P = 0.015 \)).

Analyzed quarterly, the median DTN time was 73 minutes (DTN time <60 minutes in 40.9%) in the last quarter (Q4 2012) before implementation and 59 minutes (DTN time <60 minutes in 50.0%) in the first quarter (Q2 2013) after implementation (Figure 1). The DTN times in the final quarter of the LC (Q4 2013) and the final quarter of data collection (Q1 2015) were not significantly lower than Q2 2013 (57 and 54 minutes versus 59 minutes). In interrupted time-series analysis (Table 3), there was a small but significant decline in DTN time preintervention by 1.3 minutes per quarter (\( P = 0.024 \)), but a larger reduction of 16.4 minutes was noted in the first quarter after implementation (level change, \( P = 0.034 \)). After the implementation, subsequent quarters have shown no further decline in DTN time (\( P = 0.623 \)). Adjusting for mode of arrival, EMS prenotification, and onset-to-arrival times, the level change (reduction in DTN time) in the first quarter post implementation was 15.5 minutes (\( P = 0.046 \)). In adjusted analysis at control sites, DTN declined by 1.61 minutes per quarter during Q1 2010 to Q1 2013 (\( P < 0.001 \)) but no significant level change occurred between Q1 and Q2 of 2013 (~1.17 minutes, \( P = 0.601 \)) or during Q2 2013 to Q1 2015 (0.55 minutes, \( P = 0.334 \)). In a combined adjusted model, the decrease in median DTN per quarter was greater in Chicago compared with St. Louis (~2.24 minutes versus ~1.60 minutes; \( P = 0.0430 \)).

Five DTN process strategies were increasingly used post implementation (Figure 2): (1) direct-to-CT scanner protocol (baseline: 0 sites; 1 year: 5 sites); (2) premixing tPA (baseline: 1 site; 1 year: 14 sites); (3) tPA before laboratory results (baseline: 3 sites; 1 year: 7 sites); (4) stroke code activation

![Table 1. Baseline Characteristics Among Patients With Ischemic Stroke at 15 PSCs in Chicago (Intervention Sites) and 15 PSCs in St. Louis (Control Sites)](image)

<table>
<thead>
<tr>
<th></th>
<th>Chicago (n=10314)</th>
<th>St. Louis (n=15261)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean age, y (SD)</td>
<td>68.3 (15.2)</td>
<td>70.3 (14.4)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Female, n (%)</td>
<td>5343 (53.0)</td>
<td>7922 (51.9)</td>
<td>0.877</td>
</tr>
<tr>
<td>Race, n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>4579 (44.4)</td>
<td>10908 (71.5)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Black</td>
<td>4621 (44.8)</td>
<td>4060 (26.6)</td>
<td></td>
</tr>
<tr>
<td>Asian/other</td>
<td>1114 (10.8)</td>
<td>293 (1.9)</td>
<td></td>
</tr>
<tr>
<td>Hispanic, n (%)</td>
<td>1176 (10.8)</td>
<td>75 (0.5)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Hypertension, n (%)</td>
<td>7921 (76.8)</td>
<td>11544 (75.6)</td>
<td>0.035</td>
</tr>
<tr>
<td>Diabetes mellitus, n (%)</td>
<td>3548 (34.4)</td>
<td>5076 (33.3)</td>
<td>0.061</td>
</tr>
<tr>
<td>Dyslipidemia, n (%)</td>
<td>3692 (35.8)</td>
<td>6784 (44.5)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Atrial fibrillation/flutter, n (%)</td>
<td>1447 (14.0)</td>
<td>2538 (16.6)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Prior stroke, n (%)</td>
<td>2661 (25.8)</td>
<td>4796 (31.4)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Overall tPA use in the ED, n (%)</td>
<td>766 (7.4)</td>
<td>1626 (10.7)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

ED indicates emergency department; PSC, primary stroke center; and tPA, tissue-type plasminogen activator.
Discussion

Using an LC model for the regional implementation of a quality improvement initiative to reduce DTN times at 15 PSCs in Chicago, we observed a major reduction of ≈15 minutes within 1 quarter of implementation. This finding was in contrast to concurrent control data from PSCs in St. Louis suggesting an intervention-specific effect rather than a secular trend. The results were sustainable over nearly 2 years since the LC ended in 2013. We also noted no increase in harm (ie, symptomatic hemorrhage) because of a rapid improvement in DTN times, whereas improved outcomes (ie, discharge home) were more common.

Other studies of process improvement in DTN time have found that steady improvements can be made over years,23 or potentially months when conducted at a single center.24,25

Table 2. Baseline Characteristics Among Patients With Ischemic Stroke Treated With Intravenous TPA in the Pre- and Postintervention Periods at Chicago PSCs

<table>
<thead>
<tr>
<th></th>
<th>Preimplementation Q1 2010 to Q1 2013 (n=366)</th>
<th>Postimplementation Q2 2013 to Q1 2015 (n=400)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean age, y (SD)</td>
<td>65.6 (15.8)</td>
<td>64.7 (15.4)</td>
<td>0.400</td>
</tr>
<tr>
<td>Female, n (%)</td>
<td>170 (46.5)</td>
<td>199 (49.8)</td>
<td>0.385</td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>149 (40.7)</td>
<td>150 (34.0)</td>
<td>0.567</td>
</tr>
<tr>
<td>Black</td>
<td>178 (48.6)</td>
<td>200 (54.7)</td>
<td></td>
</tr>
<tr>
<td>Asian/other</td>
<td>39 (10.0)</td>
<td>50 (7.4)</td>
<td></td>
</tr>
<tr>
<td>Hispanic, n (%)</td>
<td>40 (10.9)</td>
<td>44 (11.0)</td>
<td>0.975</td>
</tr>
<tr>
<td>Hypertension, n (%)</td>
<td>272 (76.3)</td>
<td>276 (73.4)</td>
<td>0.121</td>
</tr>
<tr>
<td>Diabetes mellitus, n (%)</td>
<td>103 (33.0)</td>
<td>96 (34.8)</td>
<td>0.221</td>
</tr>
<tr>
<td>Dyslipidemia, n (%)</td>
<td>100 (33.1)</td>
<td>113 (30.8)</td>
<td>0.837</td>
</tr>
<tr>
<td>Atrial fibrillation/flutter, n (%)</td>
<td>53 (12.4)</td>
<td>58 (11.0)</td>
<td>0.994</td>
</tr>
<tr>
<td>Prior stroke, n (%)</td>
<td>62 (24.4)</td>
<td>75 (24.8)</td>
<td>0.576</td>
</tr>
<tr>
<td>Mode of arrival, n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EMS from scene to ED</td>
<td>269 (73.5)</td>
<td>287 (71.8)</td>
<td>0.002</td>
</tr>
<tr>
<td>Private transport to ED</td>
<td>62 (16.9)</td>
<td>96 (24.0)</td>
<td></td>
</tr>
<tr>
<td>Unknown</td>
<td>35 (9.6)</td>
<td>17 (4.3)</td>
<td></td>
</tr>
<tr>
<td>EMS prenotification,* n (%)</td>
<td>197 (73.2)</td>
<td>205 (71.4)</td>
<td>0.703</td>
</tr>
<tr>
<td>Onset to ED arrival times, n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–60 min</td>
<td>213 (58.2)</td>
<td>217 (54.3)</td>
<td>0.417</td>
</tr>
<tr>
<td>61–120 min</td>
<td>105 (28.9)</td>
<td>121 (30.3)</td>
<td></td>
</tr>
<tr>
<td>121–180 min</td>
<td>30 (8.2)</td>
<td>31 (7.8)</td>
<td></td>
</tr>
<tr>
<td>181–270 min</td>
<td>10 (2.7)</td>
<td>13 (3.3)</td>
<td></td>
</tr>
<tr>
<td>&gt;270 min or unknown</td>
<td>8 (2.2)</td>
<td>18 (4.5)</td>
<td></td>
</tr>
<tr>
<td>Median onset to ED arrival time in minutes (range)</td>
<td>53 (1–237)</td>
<td>56 (3–240)</td>
<td>0.751</td>
</tr>
<tr>
<td>Median OTT in minutes (range)</td>
<td>151 (55–295)</td>
<td>131 (40–273)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Median DTN time in minutes (range)</td>
<td>82 (13–205)</td>
<td>58 (14–202)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Median door-to-CT time in minutes (range)</td>
<td>18 (0–155)</td>
<td>16 (0–121)</td>
<td>0.723</td>
</tr>
<tr>
<td>Median initial NIHSS score (range)†</td>
<td>10 (0–40)</td>
<td>9 (0–38)</td>
<td>0.092</td>
</tr>
<tr>
<td>Symptomatic intracranial hemorrhage, n (%)</td>
<td>12 (3.3)</td>
<td>12 (3.0)</td>
<td>0.989</td>
</tr>
<tr>
<td>Discharge home, n (%)</td>
<td>113 (30.9)</td>
<td>158 (39.5)</td>
<td>0.016</td>
</tr>
</tbody>
</table>

CT indicates computed tomography; DTN, door-to-needle; ED, emergency department; EMS, emergency medical services; NIHSS, National Institutes of Health Stroke Scale; OTT, onset to treatment; PSC, primary stroke center; and tPA, tissue-type plasminogen activator.

*Among those with EMS mode of arrival

†Available in 311 (85.0%) patients pre implementation and 365 (91.3%) patients post implementation.

at triage (baseline: 4 sites; 1 year: 13 sites); and (5) streamlined consent process (baseline: 0 sites; 1 year: 12 sites). Four hospitals achieved Target Stroke Honor Roll during the study year. Site-level best practice implementation is shown in Table in the Data Supplement.
However, rapid DTN improvement in a multicenter collaborative has not been previously reported upon. Our results shed light into the rapid pace of process improvement that can be expected using an LC model at multiple PSCs within a geographic region. Furthermore, this model could be applied to other aspects of stroke care, such as workflow improvements for endovascular therapy.

Although practices such as direct to CT\textsuperscript{21,23–25} and avoiding delay waiting for coagulation tests\textsuperscript{26–29} in nonanticoagulated stroke patients gained some acceptance from baseline to 1-year assessment, 3 best practice strategies (earlier stroke team activation, premixing tPA,\textsuperscript{23,25} and streamlined consent processes)\textsuperscript{30} were newly implemented at a majority of sites. Although we cannot ascribe the causality of best practice

**Table 3. Unadjusted and Adjusted Interrupted Time-Series Analysis of the Effect of the Learning Collaborative on DTN Times in Minutes in Chicago and St. Louis**

<table>
<thead>
<tr>
<th>Parameter Estimate (95% Confidence Interval)</th>
<th>P Value</th>
</tr>
</thead>
</table>
| **Chicago**
| Unadjusted analysis                          |         |
| b1, Preimplementation trend                  | −1.32   | (−2.41 to −0.24) | 0.024 |
| b2, Level change immediately postimplementation | −16.43 | (−30.87 to −1.99) | 0.034 |
| b3, Postimplementation trend                 | 0.62    | (−1.90 to 3.14)  | 0.623 |
| Adjusted analysis*                           |         |
| b1, Preimplementation trend                  | −1.38   | (−2.53 to −0.24) | 0.028 |
| b2, Level change immediately postimplementation | −15.51 | (−29.95 to −1.06) | 0.046 |
| b3, Postimplementation trend                 | 0.63    | (−1.96 to 3.23)  | 0.627 |
| **St. Louis**
| Unadjusted analysis                          |         |
| b1, Preimplementation trend                  | −1.62   | (−2.12 to −1.13) | <0.001 |
| b2, Level change immediately postimplementation | −1.75  | (−5.79 to 2.29)  | 0.391 |
| b3, Postimplementation trend                 | 0.61    | (−0.46 to 1.68)  | 0.261 |
| Adjusted analysis*                           |         |
| b1, Preimplementation trend                  | −1.61   | (−2.18 to −1.05) | <0.0001 |
| b2, Level change immediately postimplementation | −1.17  | (−5.64 to 3.29)  | 0.601 |
| b3, Postimplementation trend                 | 0.55    | (−0.57 to 1.68)  | 0.334 |

CT indicates computed tomography; and EMS, emergency medical services.

*Adjusted for mode of arrival, onset-to-arrival time, and EMS prenotification.
implementation and individual patient care, we speculate that these key practice changes were mediators of the aggregate improvement we observed.

In addition to EMS use and prenotification, patient factors such as earlier hospital arrival after stroke symptom onset, paradoxically, have been associated with delay in DTN time. Therefore, we adjusted for onset-to-arrival times, proportion of EMS use, and prenotification in prespecified analyses. Other patient factors such as stroke severity (mild and severe) and age, which might cause delays because of uncertainty in decision making, were not different between time periods.

Our postimplementation DTN times are similar to national averages in 2013 and 2014 after the Target Stroke Initiative. This suggests that Chicago regional hospitals were lagging behind and unable to implement strategies successfully before the LC model. All participating hospitals were aware of the Target Stroke Initiative from its inception in 2011. However, implementation of several best practices had not occurred until the LC model. It is possible that the national program did not resonate regionally for a variety of reasons. Recommended tools and practices may have seemed opaque and difficult to implement without opportunities to discuss with other practitioners and programs. In addition, the LC may have promoted real-world application and problem solving for best practice implementation and established accountability and competition that previously did not exist.

Although our results have been sustained since the LC, continued improvement in DTN time has not occurred. Without recurring LC activities after 2013, PSCs may not have initiated new strategies to further reduce DTN times. However, the median DTN times currently in the United States and Europe are similar to our regional results (eg, 50–60 minutes). Additional reductions may also be more challenging without substantial redesign of the DTN process of care. For example, a direct-to-CT protocol that transports suspected stroke patients to the CT scanner immediately on hospital arrival (eg, skipping bed assignment) can reduce door-to-CT times to <5 minutes and reduce DTN times significantly. However, it requires coordination between EMS, emergency medicine physicians, radiologists, and technicians and was only implemented at a minority of our hospitals. In addition, we have observed that communication and diagnostic delays related to ascertainment of medical history and time of onset, arriving at stroke diagnosis, and obtaining consent may require complex process redesigns.

Our study has several limitations. First, using the GWTG-Stroke registry, we relied on local site abstraction of data and cannot independently corroborate data accuracy. A previous national study found >90% accuracy on central auditing of records in the GWTG-Stroke registry. Second, we could not evaluate the impact of DTN process improvement on diagnostic error such as an increase in stroke mimic treatment because mimics are not uniformly entered into the GWTG-Stroke...
registry across sites. Third, a small but significant decline in DTN time was present before our intervention; therefore, we cannot discount the effect of other temporal or secular trends that we may have been unaware of. Fourth, we are unable to analyze at the individual patient level whether key strategies such as earlier activation at triage, direct-to-CT, or streamlined consent lead to reductions in DTN time. Fifth, we did not account for hospital factors such as teaching status, length of time as a PSC and GWTG-Stroke participating site, and greater experience as measured by annual tPA treatments, which may affect DTN time. Furthermore, as part of the LC agreement, we were not permitted to analyze data at the hospital level. Finally, the modest incentives both for participation in the LC and for achievement as Target Stroke Honor Roll hospital during the study period may have provided motivation and impetus for change that may have otherwise been lacking. However, the sustained results in the years after the incentives were received suggest financial rewards played a limited role.

Conclusions
Using an LC model, we successfully implemented strategies to reduce DTN times among 15 PSCs in Chicago. Compared with concurrent controls, we noted a 15-minute improvement within 1 quarter of implementation, which was sustained over the subsequent 2 years. We recommend the use of structured regional LC models for rapid and sustainable system-wide quality improvement in stroke care.

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Disclosures
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Regional Learning Collaboratives Produce Rapid and Sustainable Improvements in Stroke Thrombolysis Times
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### SUPPLEMENTAL MATERIAL

#### Supplemental Table

<table>
<thead>
<tr>
<th>Site</th>
<th>New best practices recommended</th>
<th>New best practices implemented</th>
</tr>
</thead>
</table>
| 1    | • Direct to CT
      |     • Pre-mix tPA
      |     • Rapid feedback
      |     • Consent aid | • Direct to CT
      |     • Pre-mix tPA
      |     • Rapid feedback
      |     • Consent aid |
| 2    | • Rapid feedback
      |     • Consent aid
      |     • Direct-to-CT | • Rapid feedback
      |     • Consent aid
      |     • Direct-to-CT |
| 3    | • Direct to CT
      |     • Pre-mix tPA
      |     • Consent aid
      |     • tPA prior to labs | • Pre-mix tPA
      |     • Consent aid
      |     • tPA prior to labs |
| 4    | • Direct to CT
      |     • Pre-mix tPA
      |     • Stroke code activation at triage
      |     • Consent aid
      |     • tPA prior to labs | • Pre-mix tPA
      |     • Stroke code activation at triage
      |     • Consent aid |
| 5    | • Direct to CT
      |     • Pre-mix tPA
      |     • EMS pre-notification
      |     • Consent aid | • Direct to CT
      |     • Pre-mix tPA
      |     • EMS pre-notification
      |     • Consent aid |
| 6    | • Direct to CT
      |     • Pre-mix tPA
      |     • Stroke code activation at triage
      |     • Consent aid
      |     • tPA prior to labs | • Pre-mix tPA
      |     • Stroke code activation at triage
      |     • Consent aid |
| 7    | • Direct to CT
      |     • Pre-mix tPA
      |     • Consent aid
      |     • tPA prior to labs
      |     • Stroke code activation at triage | • Direct to CT
      |     • Pre-mix tPA
      |     • Consent aid
      |     • tPA prior to labs |
| 8    | • Stroke code activation at triage
      |     • Consent aid
      |     • Pre-mix tPA
<pre><code>  |     • tPA prior to labs | • Stroke code activation at triage |
</code></pre>
<table>
<thead>
<tr>
<th>Page</th>
<th>Steps</th>
</tr>
</thead>
</table>
| 9    | - Consent aid  
     | - Pre-mix tPA  
     | - Direct to CT  
     | - tPA prior to labs  
     | - Stroke code activation at triage |
| 10   | - Direct to CT  
     | - Rapid stroke code activation  
     | - Pre-mix tPA  
     | - Stroke code activation at triage  
     | - Consent aid  
     | - tPA prior to labs |
| 11   | - Direct to CT  
     | - Pre-mix tPA  
     | - Consent aid  
     | - Stroke code activation at triage  
     | - EMS-ED handoff  
     | - tPA prior to labs |
| 12   | - Direct to CT  
     | - Pre-mix tPA  
     | - Stroke code activation at triage  
     | - Consent aid  
     | - tPA prior to labs |
| 13   | - Direct to CT  
     | - Pre-mix tPA  
     | - tPA prior to labs  
     | - Stroke code activation at triage  
     | - Consent aid |
| 14   | - Direct to CT  
     | - Pre-mix tPA  
     | - Stroke code activation at triage  
     | - Consent aid  
     | - tPA prior to labs |
| 15   | - Direct to CT  
     | - Pre-mix tPA  
     | - Consent aid  
     | - Stroke code activation at triage  
     | - tPA prior to labs |
Supplemental Figure 1: Map of 15 participant PSCs and annual stroke cases by zip code in 2011
Supplemental Figure 2: Survey questions of best practices for door-to-needle in stroke thrombolysis used in baseline and 1-year follow-up

1. Do you enter 100% of acute ischemic stroke patients into Get With The Guidelines?

Answer Options

Yes
No

2. Which of the following best practices are currently in place at your hospital?

Answer Options

Advance hospital notification by EMS
Rapid triage protocol and stroke team notification.
Single call or pager activation system
Stroke tools (checklists, order sets)
Direct to CT from triage
Rapid acquisition (<25 min) and interpretation of brain imaging (<45 min)
Rapid laboratory testing (<45 min)
Mix rt-PA medication ahead of time
Rapid access to intravenous rt-PA
Team-based approach
Provide rapid feedback

3. If suspected stroke, when do you activate the stroke team?

Answer Options

At pre-notification (if applicable)
At registration
At triage
After ED physician evaluation
Other (please specify)

Other (please specify)

4. What is required or standard process for stat CT imaging?

Answer Options

Registration complete
Order placed
Calling ahead to Radiology
Scheduling
5. Which of the following criteria do you use to activate stroke team?

**Answer Options**

- tPA patients only (using checklist)
- Abnormal stroke screen (CSS or FAST or similar screening scale)
- Time of onset < 3 hours
- Time of onset < 4.5 hours
- Time of onset < 6 hours
- Time of onset < 8 hours
- Time of onset < 12 hours
- All suspected stroke or TIA (no time window)
- Other (please specify)

6. Who is activated in stroke team page?

**Answer Options**

- Stroke Resident
- Stroke Nurse
- Stroke Attending
- CT Technician
- Transport
- Social Worker
- Pharmacist
- Laboratory Technician
- Interventional Team Member
- Other (please specify)

7. Who decides to give tPA to eligible patients in the ED?

**Answer Options**

- ED physician with stroke attending after in-person evaluation
- ED physician with stroke attending after telemedicine evaluation
- ED physician with stroke attending by phone
ED physician with stroke fellow after in-person evaluation
ED physician with stroke fellow by phone
ED physician with junior in-house neurology resident (PGY 2)
ED physician with senior in-house neurology resident (PGY 3 or 4)
ED physician with senior neurology resident by phone (PGY 3 or 4)
ED physician with in-house physician extender (NP or PA)
Ed physician without neurology input
Other (please specify)

Other (please specify)

8. Do you require waiting for lab results before giving tPA?

Answer Options
Yes, all of the time (no point-of-care labs used)
Yes, all of the time (point-of-care labs used)
Yes, with rare exceptions
No, only in certain rare instances
Never

9. Where is tPA stored?

Answer Options
ED pyxis
Pharmacy
Other (please specify)

Other (please specify)

10. Who re-constitutes, prepares and doses tPA?

Answer Options
ED Nurse
Pharmacist
Both
Other (please specify)

Other (please specify)

11. Do you have a direct-to-CT protocol in place?
**12. When do you start pre-mixing tPA?**

**Answer Options**
- Never
- In select cases if high likelihood (after CT scan)
- In select cases if high likelihood (before CT scan)

**13. Do you currently use AHA QUESTS standardized consent template card?**

**Answer Options**
- Never
- Sometimes
- Always

**14. Do you have tPA in your ED 24/7?**

**Answer Options**
- Yes
- No

**15. Do you provide real-time (within 1 week) feedback to your team (for example, using a DTN scorecard)?**

**Answer Options**
- Yes
- No