Reducing Door-to-Reperfusion Time for Mechanical Thrombectomy With a Multitiered Notification System for Acute Ischemic Stroke

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Abstract

**Objective:** To reduce door-to-angiographic reperfusion (DTR) time to 120 minutes for patients presenting with acute ischemic stroke attributed to anterior circulation large-vessel occlusion amenable to endovascular mechanical thrombectomy.

**Patients and Methods:** Patients treated with mechanical thrombectomy before (April 10, 2015, through April 11, 2016) and after (April 12, 2016, through May 10, 2017) implementation of a multitiered notification system were studied. Lean process mapping was used to assess inefficiencies with multidisciplinary triage. A 3-tiered paging platform, which rapidly alerts essential personnel of the acute ischemic stroke team at advancing decision points, was introduced.

**Results:** Sixty-two patients were analyzed before and after implementation (34 vs 28, respectively). Following intervention, DTR time was reduced by 43 minutes (mean DTR, 170 minutes vs 127 minutes; \( P = .02 \)). At 90-day follow up, 5 of the 28 patients in the postintervention cohort (19%) had excellent neurologic outcomes, defined as a modified Rankin Scale score of 0, compared to 0 of 34 (0%) in the preintervention cohort (\( P = .006 \)). Reductions were also seen in the length of stay on the neurocritical care service (mean, 6 vs 3 days; \( P < .001 \)), and total hospital charges for combined groups (mean, $100,083 vs $161,458; \( P < .001 \)).

**Conclusion:** The multitiered notification system was a feasible solution for improving DTR within our institution, resulting in reductions of overall DTR time, neurocritical care service length of stay, and total hospital charges.

**S**troke is a leading cause of serious long-term disability in the United States, with roughly 1 of every 20 deaths attributed to stroke. Globally, stroke is the second leading cause of death, accounting for 11.8% of all deaths worldwide. Approximately 85% of all strokes are due to an abrupt interruption of blood flow causing an acute ischemic stroke (AIS). Since 1996, the United States Food and Drug Administration has approved the use of human recombinant tissue plasminogen activator (rtPA) for...
intravenous (IV) thrombolysis for patients with AIS. However, 45% of AISs are due to proximal anterior circulation large-vessel occlusion (LVO), for which IV rtPA alone has an estimated recanalization rate of only 30%.2-4 For patients presenting with LVO of the anterior circulation, endovascular mechanical thrombectomy (MT) substantially improves rates of recanalization—with or without adjuvant IV rtPA. Multiple randomized controlled trials have reported that recanalization by MT has been associated with improved outcomes.5-11

The benefit of MT on functional recovery is time sensitive. The American Heart Association/American Stroke Association recommends that eligible patients undergo MT preferably within 6 hours but up to 24 hours if ischemic penumbra is present.12 Delays in achieving reperfusion with MT are associated with increased long-term morbidity, highlighting the need to identify inefficiencies in emergency triage.13 Door-to-angiographic reperfusion (DTR), defined as the time between arrival in the emergency department (ED) to angiographically proven large-vessel recanalization, serves as a surrogate clinical marker for the efficiency of pathways to MT.14 The aim of this quality improvement project was to decrease DTR time to a target goal of 120 minutes within 12 months, with the goal of improving patient outcomes.

PATIENTS AND METHODS

Study Population
A prospective study was performed within Mayo Clinic in Florida of patients treated with MT before (April 10, 2015, through April 11, 2016) and after (April 12, 2016, through May 10, 2017) implementation of a multitiered notification system. Through standard institutional practices for AIS, patients presented to either the ED or as a hospital transfer. Patients with AIS considered for MT met the following criteria: National Institutes of Health Stroke Scale (NIHSS) score of 6 or greater, anterior circulation LVO on computed tomography (CT) angiogram, Alberta Stroke Program Early CT Score (ASPECTS) greater than 6, and patients with wake-up stroke or unknown time of onset. Figure 1 illustrates the preintervention decision pathway for patients presenting with AIS. Inefficiencies of patient triage within the ED and interdisciplinary communication were identified as targets for improvement based on current state process mapping.

Intervention
The proposed solution was the implementation of a 3-tiered paging platform coordinated through the telephone operators, with escalating tiers based on the probability for MT triggering involvement of key team members (Figure 1).

Tier 1. Tier 1 is activated by the ED or prehospital emergency medical services for patients presenting with acute neurologic symptoms either within 12 hours of witnessed symptom onset, unknown time of symptom onset, or symptoms present on awakening. The vascular neurology resident, CT technician, radiology resident, and nursing house supervisor are paged simultaneously, initiating the Tier 1 AIS protocol. The personnel paged have discrete roles: the neurology resident is responsible for initial patient assessment and implementation of the stroke protocol; the CT technician prepares the scanner; the radiology resident is responsible for immediate interpretation of imaging; and the nursing house supervisor is responsible for providing adequate staffing.

On arrival at the ED, the patient is immediately evaluated in a dedicated alcove adjacent to the ambulance bay/air transport entrance and the CT scanner. Intravenous rtPA is administered to eligible patients during Tier 1 while the patient is simultaneously being evaluated for advancement through the tier system. If the patient is determined to not be a candidate for MT or if an alternative diagnosis to AIS is made (eg, stroke mimic or intracranial hemorrhage), the tier system is terminated with a cancellation page requested by the neurology resident through the institutional operator.

Tier 2. If, on the initial evaluation by the vascular neurology resident, clinical findings are suggestive of a possible LVO (eg, gaze deviation, aphasia, neglect) activation of Tier 2 notification is made through the telephone operators. Intravenous rtPA is administered to eligible patients during Tier 1 while the patient is simultaneously being evaluated for advancement through the tier system. If the patient is determined to not be a candidate for MT or if an alternative diagnosis to AIS is made (eg, stroke mimic or intracranial hemorrhage), the tier system is terminated with a cancellation page requested by the neurology resident through the institutional operator.
**FIGURE 1.** Preintervention decision pathway and subsequently implemented 3-tier notification system. Top, The process map shows the original track for patients presenting as either a hospital-to-hospital transfer or as an emergency department (ED) arrival. Bottom, A multitiered paging platform was introduced for patients presenting with acute ischemic stroke due to large-vessel occlusion. APP = advanced practice provider; CT = computed tomography; CTA = CT angiography; CTP = CT perfusion; EMS = emergency medical services; IV = intravenous; NIHSS = National Institutes of Health Stroke Scale; RN = registered nurse; rtPA = human recombinant tissue plasminogen activator.

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### Procedure Time

| Tier 1 Possible ischemic stroke | Tier 2 Probable intervention | Tier 3 Definite intervention |
|--------------------------------|-----------------------------|------------------------------|
| Neurology Resident*            | Neurology Resident*         | Neurology resident           |
| ED team leader                 | ED                           | Neurointervention            |
| Radiology                      | - Team leader                | - RN and technician*         |
| - Resident                     | - Consultant                 | - Neurosurgery APP*          |
| - CT technician*               | - Resident                   | - Anesthesia consultant      |
| House supervisor               | - CT technician*             | Nursing                      |
|                               |                              | - House supervisor           |
|                               |                              | - Charge nurse               |
|                               |                              | Neurocritical care APP       |

### Activated by EMS:

- New neurologic deficits
- Within 12 hours of known onset time
- Unknown time of onset
- Wake-up symptoms

- Exam suggesting large-vessel occlusion
- Signs of large-vessel occlusion
- Vessel imaging revealing clot

* = Requires callback to the telephone operator

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**Door to image 17 min**

**Door to decision 106 min**

**Door to suite 108 min**

**Door to revascularization first pass 215 min**

**Door to image 17 min**

**Door to decision**

**Door to suite 37 min**

**Door to revascularization first pass 141 min**

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* = Data not available
2 notification is activated when the NIHSS score is 6 or greater, when noncontrast head CT reveals a hyperdense vessel sign, or when CT angiography demonstrates an LVO.

Team members notified by Tier 2 activation include those alerted on the Tier 1 page as well as the neurointervention fellow, neurosurgery resident or advanced practice provider, the neurointervention suite staff, anesthesia consultant and nursing staff, neurocritical care service (NCC) consultant, ED consultant, and unit nursing supervisors. A Tier 2 escalation prompts an initial assessment for an endovascular procedure. The ED consultant is notified to keep him/her apprised of the treatment decisions in real time. The neurointervention fellow is paged to clinically evaluate the patient, review the available neuroimaging, update the neurointervention consultant of the case, and obtain consent for the procedure. In parallel, the anesthesia consultant and the neurointervention suite staff can prepare for an anticipated procedure. Computed tomographic angiography and perfusion studies are performed during this tier, allowing for identification of thrombus, mapping of the vasculature, and assessment for salvageable penumbra, all while IV rtPA is being infused. Off-hours Tier 2 pages require home-call team members to emergently mobilize to the hospital.

For MT candidates arriving as hospital transfers, the transfer center activates the Tier 2 page with an estimated time of arrival. For these patients, Tier 1 status is not generally applicable because these patients have already been evaluated for IV rtPA at the transferring institution either remotely by Mayo Clinic neurology staff or by phone with the neurointervention consultant. On arrival, if the patient is not eligible for MT, they are admitted for comprehensive stroke care. Should MT not be offered, this tier may be de-escalated by calling the in-house operator to downgrade the treatment page. If MT is not eligible, the patient may still occur should the patient’s clinical condition deteriorate (eg, respiratory failure, status epilepticus, cerebral herniation), if the family elects not to proceed, or if additional information is obtained that precludes MT.

### Data Collection and Analysis

Data were obtained from patients preceding the intervention (April 10, 2015, through April 11, 2016) and following implementation of the intervention (May 10, 2016, through May 10, 2017). None of the patients within the postintervention group were also seen in the preintervention group. Statistical analysis was performed by one of the authors (E.D.G.) using a Mann-Whitney U test and χ² test for assessment of significance. Data were collected by one of the authors (E.D.G.) and Mayo Clinic Quality Management Services. Retrospective ASPECTS, which provides a 10-point topographical evaluation of early ischemic changes on noncontrast head CT within the middle cerebral artery distribution, was obtained through medical record documentation and was interpreted by one of the authors (E.D.G.) when absent. The modified Rankin Scale (mRS) score was obtained either by a 90-day poststroke outpatient follow-up visit or by phone interview (L.M.). Utility-weighted mRS score was derived from the obtained mRS values, with utility values of 1.0 for mRS 0, 0.91 for mRS 1, 0.76 for mRS 2, 0.65 for mRS 3, 0.33 for mRS 4, and 0 for mRS 5 and 6. Hospital and professional charges were supplied by the financial department. Mean and median DTR times and functional outcomes measured by mRS score at 90 days poststroke served as primary outcomes.

### RESULTS

Thirty-four patients were treated in the preintervention group (15 ED arrivals and 19 hospital transfers). Twenty-eight patients were treated in the postintervention group (12 ED arrivals and 16 hospital transfers). The cohorts’ demographic characteristics including age, sex, and vascular risk factors as well as arrival NIHSS score were similar.
Initial CT ASPECTS was higher in the postintervention group, although not significantly ($P=0.99$). Thrombus location within the anterior circulation, notably involving the carotid terminus, was similar between preintervention and postinterventional groups (carotid terminus, $7 \text{ vs } 5$), as well as the percentage of patients who received adjuvant IV rtPA (59% [20 of 34] vs 46% [13 of 28]; $P=0.38$) (Table). No tandem occlusions were reported.

Before implementation of the multtiered paging platform, patients arriving through the ED had a DTR median time of 215 minutes, with a range of 116 to 434 minutes. Preintervention hospital transfers had a median DTR of 125 minutes with a range of 71 to 215 minutes. The overall DTR time for preintervention patients was a median of 129 minutes. Following introduction of the multtiered paging platform, patients arriving through the ED had a DTR median time of 139.5 minutes, with a range of 94 to 364 minutes ($P=0.008$). Hospital transfers had a median DTR time of 104.5 minutes and a range of 64 to 131 minutes ($P=0.36$). The overall DTR for postintervention patients was a median of 114.5 minutes and a range of 64 to 364 minutes ($P=0.02$) (Figure 2). In the preintervention cohort, symptom onset or last known normal time to angiographic reperfusion (LTR) had a median of 399 minutes with a range of 151 to 868 minutes, while in the postintervention group median time was 328 minutes with a range of 148 to 1150 minutes ($P=0.22$). For those who arrived in the ED, the median LTR was 506 minutes in the preintervention group and 233 minutes in the postintervention group (range of 280 to 868 minutes and 148 to 890 minutes, respectively; $P=0.02$). Hospital transfers had a

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| Variable                              | Preintervention (n=34) | Postintervention (n=28) | $P$ value |
|---------------------------------------|------------------------|-------------------------|-----------|
| Age (y)                               | 67.5 (38-93)           | 70 (51-93)              | 0.50      |
| Female sex                            | 11 (32)                | 15 (54)                 | 0.50      |
| White                                 | 28 (82)                | 28 (100)                | 0.50      |
| Arterial hypertension                 | 26 (76)                | 26 (93)                 | 0.50      |
| Diabetes mellitus type 2              | 9 (26)                 | 9 (32)                  | 0.50      |
| Atrial fibrillation                   | 18 (53)                | 14 (50)                 | 0.50      |
| Past or current nicotine use          | 11 (32)                | 5 (18)                  | 0.50      |
| BMI (kg/m²), mean ± SD                | 27±6                   | 29±8                    | 0.50      |
| Arrival NIHSS score                   | 19 (3-31)              | 17.5 (4-36)             | 0.50      |
| Arrival CT ASPECTS                    | 7 (3-10)               | 8 (6-10)                | 0.99      |
| IV intravenous human recombinant      | 20 (59)                | 13 (46)                 | 0.38      |
| tissue plasminogen activator          |                        |                        |           |
| Thrombus location                     | NA                     | NA                      |           |
| Preterminal ICA                       | 1                      | 1                       |           |
| Carotid terminus                      | 7                      | 5                       |           |
| Proximal MCA                          | 8                      | 8                       |           |
| Distal MCA                            | 11                     | 10                      |           |
| M2 segment                            | 7                      | 4                       |           |
| Complications                         | NA                     | NA                      |           |
| Malignant cerebral edema              | 6                      | 1                       |           |
| Intralesional hemorrhage$^{17}$       | 6 (4 PH1, 1 PH2, 1 HI2)| 6 (3 PH1, 1 PH2, 2 HI1)|           |
| Periprocedural SAH                     | 1                      | 1                       |           |
| Infection (eg, UTI, HAP)              | 3                      | 1                       |           |
| Other (eg, gout flare)                | 1                      | 0                       |           |

$^{1}$ASPECTS = Alberta Stroke Program Early Computed Tomography Score; BMI = body mass index; CT = computed tomography; HAP = hospital-associated pneumonia; HI1, HI2 = hemorrhagic infarction types 1 and 2; ICA = internal carotid artery; IV rtPA = intravenous recombinant tissue plasminogen activator; MCA = middle cerebral artery; NA = not applicable; NIHSS = National Institutes of Health Stroke Scale; PH1, PH2 = parenchymal hemorrhage types 1 and 2; SAH = subarachnoid hemorrhage; UTI = urinary tract infection.

$^{2}$Data are presented as median (range) or No. (percentage) unless indicated otherwise.
FIGURE 2. Door-to-reperfusion time and neurocritical care length of stay before and after intervention. Door-to-reperfusion time was reduced significantly by a mean of 43 minutes when including both ED arrivals and hospital-to-hospital transfers ($P = .02$). Emergency department arrivals alone saw a mean reduction of 70 minutes. Patients admitted to the neurocritical care service had a mean reduction of 3 days.
preintervention median of 320 minutes compared to 410 minutes in the postintervention group (P=.94), with a range of 151 to 715 minutes and 227 to 1150 minutes, respectively.

A favorable Thrombolysis in Cerebral Infarction (TICI) score, which is a measurement of the degree of reperfusion following recanalization, defined as TICI 2b or 3, was similar between the 2 groups. Total hospital length of stay was similar between both groups; however, the total length of stay in the NCC service significantly decreased for hospital transfers (median [range], 4 days [2-21 days] vs 3 days [1-9 days]; P=.002) and overall (median [range], 4 days [2-21 days] vs 3 days [1-9 days]; P=.006) (Figure 2). Using the magnetic resonance imaging–based classification scheme for hemorrhagic transformation by the European Cooperative Acute Stroke Study, both the preintervention and postintervention groups had 6 hemorrhagic transformations (4 PH [parenchymal hemorrhage] type 1, 1 PH2, 1 HI [hemorrhagic infarction] type 2 vs 3 PH1, 1 PH2, 2 HI1). None of the hemorrhagic transformations were associated with clinical worsening of the NIHSS score and thus are considered asymptomatic. Malignant cerebral edema was different between the preintervention and postintervention groups (6 vs 1, respectively; P=.13), with 5 of the preintervention patients requiring decompensative hemicraniectomy and 1 transitioning to hospice care, whereas the 1 patient in the postintervention group was treated medically with hypertonic saline. Hospital-acquired complications, such as infection, were similar between groups (Table).

Analysis of discharge disposition revealed similar rates of transition to short-term rehabilitation facilities and to home with or without home health care assistance. There was a decrease in inpatient deaths that did not reach statistical significance (18% [6 of 34] vs 4% [1 of 28]; P=.16) (Figure 3). Ninety-day poststroke assessments were performed via telephone interview or outpatient follow-up to determine mRS scores. The mean mRS scores were 3.9 for preintervention patients and 3.5 for the postintervention group (P=.09), with similar rates of functional independence (mRS score, ≤2) (P=.98) and ability to ambulate unassisted (mRS score, ≤3) (P=.93) between the groups. The mean utility-weighted mRS score was .40 and .44 for the preintervention and postintervention groups, respectively. On 90-day follow-up, 5 of the 28 postintervention patients (19%) had an mRS score of 0 (or no measurable deficits) compared to 0 of the 34 preintervention patients (0%). Patient death at 90 days was not considerably different between the 2 groups (Figure 3). Overall charges were significantly less for postintervention patients than for preintervention patients (total mean, $100,083 vs $161,458; P<.001) (Figure 4).

DISCUSSION
Streamlined treatment of patients presenting with AIS is critical to reduce long-term morbidity and mortality. Recent studies have shown that MT is crucial for reperfusion of anterior cerebral circulation LVO. However, the large size of the acute stroke team needed to offer MT increases the complexity of coordinating this treatment efficiently. We were able to identify sources of substantial delay within the treatment pathway for emergent MT, namely, interdepartmental communication and timely preparation and staffing of the neurointerventional suite. The 3-tiered notification system was introduced, which allowed for rapid and universal communication to key members of the AIS team. Through this process, key personnel could be activated at the appropriate time without delay, and critical assessments and preparation needed to get the patient to MT could be performed in parallel. The median DTR time difference, 75.5 minutes, was largest for patients who arrived through our ED, where patients often arrive without advance notice. Patients who were hospital transfers had a 20.5-minute reduction in median DTR. We hypothesize that the minimal improvement seen within the hospital transfer group was due to multiple factors such as pretransfer confirmation of LVO, initiation of IV thrombolysis in eligible candidates, preestablished IV access, preobtained medical history and last known normal time prior to arrival, and early notification of arrival times of patients.

In the United States, where a large proportion of patients are reaching advanced age, the economic burden of ischemic stroke on the national health care systems is of increasing importance. For every 15-minute reduction in DTR time, there is a 2.5% increase in functional independence for patients with LVO.
This effect has not only profound implications for patients and families but also a tremendous reduction in economic burden by reducing patient disability. Our data demonstrated a reduction of total charges by $61,375, indicative of a substantial reduction in direct medical costs. However, indirect costs are the greatest contributor to lifetime economic impact for AIS with estimates for lifetime per-person costs of $97,500 in 1990, approximating $184,011 when adjusted for inflation in 2018.10 Following implementation of our paging platform, 1 in 5 patients who presented with AIS due to LVO had no functional deficits on 90-day follow-up. This improved outcome will predictably lead to a substantial reduction in downstream costs (eg, lost earnings, in-home medical assistance, rehabilitation, and disability devices) attributed to efficient AIS treatment pathways.20

Our data reinforce the case for appropriate patient selection criteria when contemplating...

FIGURE 3. Disposition from hospital and 3-month modified Rankin Scale scores before and after intervention. Top frame illustrates postdischarge locations for patients presenting both before and after implementation of the tier paging platform. Bottom frame shows the percentages of 3-month modified Rankin Scale scores without the 2 cohorts.
benefit from MT. In the preintervention cohort, patients arriving as a hospital transfer had lower CT ASPECTS on presentation, indicative of larger regions of irreversible brain damage associated with an increased number of cases of hemorrhagic transformation and malignant cerebral edema requiring hemicraniectomy despite having similar recanalization rates. Attention to patient selection will become pivotal to achieving favorable patient outcomes because recent studies such as the DAWN (Diabetic Attitudes, Wishes, and Needs) and DEFUSE-3 (Endovascular Therapy Following Imaging Evaluation for Ischemic Stroke 3) trials indicate benefit for carefully selected patients outside the traditional time windows that had previously dictated patient eligibility to receive any acute stroke treatment.11,21 We did note favorable functional outcomes to be lower than previously published outcomes, but review of our patient data indicated that we included patients that would not have been eligible for these larger multicenter studies based on the inclusion and exclusion criteria of the HERMES (Highly Effective Reperfusion Evaluated in Multiple Endovascular Stroke) meta-analysis and our LTR times.10

This quality improvement project has several limitations. Foremost, the sample size is small, which may not reveal statistically significant changes within small degrees of improvement. Additionally, the preintervention data was obtained retrospectively, which limited availability of some data such as door-to-groin puncture time; thus this was a metric that could not be reported in this study. Prospective data collection now includes door-to-groin puncture time as a key metric within the process pathway. Hospital transfers had several outliers due to distance of transfer and unknown last known normal within the postintervention group when evaluating LTR, which inflated the postintervention median LTR times. Future directions include initiatives to obtain prehospital medical history and onset times, identify AIS patients with possible LVO earlier, and facilitate rapid time to imaging protocols.

CONCLUSION

We implemented a multitiered paging platform at our institution that proved to be a feasible solution for improving DTR times for acute stroke patients. The tier to paging

FIGURE 4. Total charges for patients presenting with acute ischemic stroke who underwent mechanical thrombectomy before and after implementation of the tier paging platform.
platform resulted in a major reduction in overall DTR times, total length of NCC stay, and total charges. This project may serve as a model for other stroke centers to improve delivery of care to patients presenting with AIS.

Abbreviations and Acronyms: AIS = acute ischemic stroke; ASPECTS = Alberta Stroke Program Early CT Score; CT = computed tomography; DTR = door-to-angiographic reperfusion; ED = emergency department; IV = intravenous; LTR = last known normal time to angiographic reperfusion; LVO = large-vessel occlusion; mRS = modified Rankin Scale; MT = mechanical thrombectomy; NIHSS = National Institutes of Health Stroke Scale; NCC = neurological care service; rtPA = human recombinant tissue plasminogen activator

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