Telemedicine in Prehospital Stroke Evaluation and Thrombolysis
Taking Stroke Treatment to the Doorstep

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**IMPORTANCE** Mobile stroke treatment units (MSTUs) with on-site treatment teams that include a vascular neurologist can provide thrombolysis in the prehospital setting faster than treatment in the hospital. These units can be made more resource efficient if the need for an on-site neurologist can be eliminated by relying solely on telemedicine for physician presence.

**OBJECTIVE** To test whether telemedicine is reliable and remote physician presence is adequate for acute stroke treatment using an MSTU.

**DESIGN, SETTING, AND PARTICIPANTS** Prospective observational study conducted between July 18 and November 1, 2014. The dates of the study analysis were November 1, 2014, to March 30, 2015. The setting was a community-based study assessing telemedicine success of the MSTU in Cleveland, Ohio. Participants were the first 100 residents of Cleveland who had an acute onset of stroke-like symptoms between 8 AM and 8 PM and were evaluated by the MSTU after the implementation of the MSTU program at the Cleveland Clinic. A vascular neurologist evaluated the first 100 patients via telemedicine, and a neuroradiologist remotely assessed images obtained by mobile computed tomography (CT). Data were entered into the medical record and a prospective registry.

**MAIN OUTCOMES AND MEASURES** The study compared the evaluation and treatment of patients on the MSTU with a control group of patients brought to the emergency department during the same year. Process times were measured from the time the patient entered the door of the MSTU or emergency department, and any problems encountered during his or her evaluation were recorded.

**RESULTS** Ninety-nine of 100 patients were evaluated successfully. The median duration of telemedicine evaluation was 20 minutes (interquartile range [IQR], 14-27 minutes). One connection failure was due to crew error, and the patient was transported to the nearest emergency department. There were 6 telemedicine disconnections, none of which lasted longer than 60 seconds or affected clinical care. Times from the door to CT completion (13 minutes [IQR, 9-21 minutes]) and from the door to intravenous thrombolysis (32 minutes [IQR, 24-47 minutes]) were significantly shorter in the MSTU group compared with the control group (18 minutes [IQR, 12-26 minutes] and 58 minutes [IQR, 53-68 minutes], respectively). Times to CT interpretation did not differ significantly between the groups.

**CONCLUSIONS AND RELEVANCE** An MSTU using telemedicine is feasible, with a low rate of technical failure, and may provide an avenue for reducing the high cost of such systems.
Acute stroke thrombolytic treatment is time sensitive and is usually delivered with the coordination of prehospital care providers and neurologists, physicians, and nurses in the emergency department (ED). Based on data from a pooled analysis of major intravenous tissue plasminogen activator (IV-tPA) trials, benefit is greater with early IV-tPA administration.1 Many patients are unable to obtain acute stroke treatment because of delays in presentation to the hospital. Studies2-4 exploring prehospital delays in stroke care have revealed that only 15% to 60% of patients having a stroke are able to reach the hospital within 3 hours of symptom onset and demonstrated that this proportion has not decreased over the last 10 years. Recently, mobile stroke units have been shown to reduce the time to evaluation and thrombolysis in Germany.5,6 These systems use an ambulance equipped with a computed tomography (CT) system and laboratory testing that brings personnel, including a neurologist, to the scene. Unlike other mobile stroke treatment units (MSTUs), the Cleveland Clinic MSTU solely uses telemedicine for physician presence. Telemedicine allows the remote presence of medical expertise and has wide clinical applications, including the evaluation of patients with acute stroke, which has proven to be highly reliable compared with in-person assessment.7-13 Two cost-effectiveness analyses of mobile stroke unit systems have suggested favorable economics, especially if the need for on-site expertise can be eliminated by relying on telemedicine.14,15 We report our initial experience with and the feasibility of an MSTU in Cleveland, Ohio, including the use of telemedicine as a substitute for physician presence, and compare the time efficiency of stroke evaluation in EDs.

Methods

Mobile Stroke Treatment Unit

The Cleveland Clinic MSTU was planned and executed as a Cleveland Clinic initiative in partnership with the City of Cleveland, the Cleveland Emergency Medical Service (EMS), and other participating hospitals within Cleveland. The MSTU is equipped with a mobile CT system (CereTom; NeuroLogica Corporation). The onboard staff consists of a registered nurse, paramedic, emergency medical technician, and CT technologist (eTable 1 in the Supplement). A vascular neurologist (VN) evaluates the patient via telemedicine, and a neuroradiologist remotely assesses images obtained by CT (Figure 1). Telemedicine and CT images are transferred via a network (long-term evolution; Verizon Wireless). The portable point-of-care laboratory equipment is able to measure the following: international normalized ratio (CoaguChek XS Pro; Roche Diagnostics), blood glucose and electrolyte levels (i-STAT System; Abbott Laboratories), and hemoglobin level and platelet and leukocyte counts (pocH 100i Hematology Analyzer; Sysmex Corporation). The MSTU also carries alteplase, antihypertensive agents, and other medications required for acute stroke and emergency care (eTable 2 in the Supplement lists all medications available).

Patients and Procedures

The Cleveland Clinic MSTU became operational on July 18, 2014. In its initial phase, the MSTU was active 12 hours daily 7 days a week from 8 AM to 8 PM and responded within the City of Cleveland (Figure 2). An orientation and descriptive handbook was provided to all individuals considered to be potentially involved with patient care on the MSTU, including all VNs, vascular neurology fellow trainees, emergency medical technician personnel, technicians, emergency physicians, and nursing staff at the Cleveland Clinic. Two weeks of mock MSTU scenarios between July 1 and July 17, 2014, were conducted before the start date, including simulations of stroke alerts that tested physician preparedness, equipment reliability, and telecommunication. In addition, we continued to conduct mock stroke alerts for quality improvement purposes.

Figure 1. Mobile Stroke Treatment Unit

A, External view. B, Internal view with a computed tomography imaging system. C, Telemedicine unit at center, with laboratory testing equipment on the counter at the right. D, Team in action.
The City of Cleveland spans 77.7 square miles, with an estimated population of 390,113 and a median household income of $26,556 annually.16 The parking base of the MSTU during the initial phase was at the main campus of Cleveland Clinic hospital, which is located approximately 4 miles east of downtown Cleveland (Figure 2). For any ambulance dispatch for possible stroke within the city, the EMS dispatcher activates both the standard city ambulance and the MSTU. The city EMS team establishes scene safety and performs initial patient evaluation, including administration of the Cincinnati Prehospital Stroke Scale.17 If stroke is still suspected, the city EMS transfers care to the MSTU team. The MSTU team obtains a brief history and assesses any instability before transferring the patient to the MSTU. For patients who are deemed not to have stroke by the city EMS team, the MSTU activation is canceled. For any simultaneous stroke calls the MSTU receives, it acts on a first-come, first-served basis and only responds to the second call after the first mission is complete. Otherwise, the city EMS team proceeds without MSTU involvement.

Once the patient is inside the ambulance, the MSTU team monitors vital signs and performs a secondary head-to-toe assessment. During initial assessment, the CT technologist registers the patient into the hospital electronic medical record. This electronic medical record is available for viewing from any of the hospitals within the Cleveland Clinic system. A physician is notified to order the CT and laboratory tests via the electronic medical record system and is able to prepare for the telemedicine encounter, including prior medical record review. On completion of the assessment, head CT is obtained. Once the CT is complete and the data transfer begins, the team obtains intravenous access to collect necessary blood samples to run the point-of-care testing and to secure appropriate access for the potential administration of intravenous medications and contrast. Once the blood samples are collected, the point-of-care tests are conducted by a team member. The patient is repositioned to optimize the telemedicine view while another team member guides the patient through the National Institutes of Health Stroke Scale, which is led by the VN via telemedicine. Treatment, including intravenous thrombolysis, is started on-site, when indicated, and is continued during transport to the receiving hospital.

The decision to transport to a particular hospital is made based on patient preference, proximity, hospital resources, and stroke type and severity. Any patient with severe stroke requiring potential endovascular treatment is triaged to a comprehensive stroke center. For patients with minor deficits or those receiving only IV-tPA, the closest Joint Commission stroke-certified hospital is chosen unless the patient prefers an alternate location. While the MSTU is in transit to the hospital, the VN conducts a physician-to-physician report with the accepting physician at the destination ED. A receiving neurologist is also directly contacted if IV-tPA was administered. The MSTU nurse calls the receiving facility with a brief report and estimated time of arrival. On arrival, the MSTU team transfers care of the patient to the receiving staff, gives a verbal report and a copy of the CT images on a compact disc, and provides an abbreviated report sheet that includes patient demographics, vital signs, and administered medications. If the patient is transported to the main Cleveland Clinic hospital, the VN notifies the stroke team to receive the patient and obtains a hospital bed in the neurological intensive care unit for the patient, bypassing the ED.

**Telemedicine**

The telemedicine network and portable equipment used in our MSTU is based on the same technology as existing hospital-based telemedicine systems, with a remote control, high-resolution medical-grade digital camera (RP-Xpress; InTouch Health). This camera is mounted on
the inner aspect of the entry gate of the ambulance to maximize the field of vision (Figure 1).

Data Collection
Data were prospectively collected, including demographics, time of the stroke call (alarm time), time of arrival to the scene, time of patient entry into the MSTU (door time), video log-in and log-out times, time of CT and laboratory testing, time of arrival to the hospital, and time of IV-tPA treatment, where applicable. Probable acute ischemic stroke was recorded if there was a moderate to strong suspicion of an ischemic stroke during the patient evaluation based on clinical or radiological features. Possible acute ischemic stroke was diagnosed if suspicion of stroke was less and no clear stroke mimic was identified. Study data were collected and managed using research electronic data capture (REDCap), a secure, web-based application designed to support data capture for research studies.18

The comparison group consisted of patients seen at EDs in the Cleveland Clinic health system directly by the City of Cleveland EMS between 8 AM and 8 PM from January 1 to December 31, 2014, for whom a stroke alert was activated within 30 minutes of arrival to the ED. To ensure that we had a comparable group, 30 minutes was chosen to exclude patients who did not initially have stroke symptoms or patients who were not transported by EMS.

Ethics
The study was approved by the Institutional Review Board at the Cleveland Clinic. No informed consent was obtained for this observational study, and research data were obtained from clinical care and quality assurance records. The dates of the study analysis were November 1, 2014, to March 30, 2015.

Statistical Analysis
The aims of the analyses were to assess the operation of the MSTU, including successful team evaluation and telemedicine connection, and to compare the time efficiency of the MSTU evaluation compared with the control ED evaluation. Medians and interquartile ranges (IQRs) were calculated. A nonparametric Wilcoxon rank sum test was used to compare the median times from the door to video log-in, CT completion, laboratory test results, and IV-tPA administration. Data analyses were performed using statistical software (JMP, version 10.0; SAS Institute Inc).

Results

Demographics and Initial Diagnosis
During our initial phase between July 18 and November 1, 2014, the MSTU was deployed 317 times, of which 217 dispatches were canceled before on-site arrival. The remaining 100 patients (31.5%) underwent urgent evaluation in the MSTU (Figure 3). A demographic profile of these patients is summarized in Table 1. An initial diagnosis of probable acute ischemic stroke was made in 33 patients (33.0%). Twenty-six of these patients (78.8%) were transferred to 1 of 3 comprehensive stroke centers. The remaining 7 patients (21.2%) received care at a Joint Commission stroke-certified hospital.

Successful Evaluation and Treatment
A telemedicine encounter was successfully completed in 99 patients (99.0%). There was one instance when the power supply to the telemedicine station on the MSTU was not switched on and video could not be initiated, which was attributed to system error. However, the MSTU transported the patient with prenotification to the nearest ED where the remainder of the stroke evaluation was performed. Ninety-three evaluations were conducted without any transmission disruptions (Table 2). The median door to video log-in time was 11 minutes (IQR, 7-17 minutes), and the median video log-in duration was 20 minutes (IQR, 14-27 minutes) (Table 1). There were 6 instances of video disconnection, of which 5 were because of an area of poor wireless reception. One disconnection was due to the use of a tablet computer by the VN to log into the telemedicine system, which was not compatible with the devices on the MSTU. No video disconnections lasted longer than 60 seconds, and they did not affect clinical care, as judged by the VN.

Ninety-nine patients (99.0%) underwent noncontrast head CT in the MSTU (Table 2). One patient could not undergo CT...
because of hemodynamic instability requiring advanced cardiac life support. There were 5 instances of CT delays, including patient agitation (n = 3) and network delays in image transfer (n = 2). Sixteen patients (16.0%) received IV-tPA in the MSTU (Table 1). One additional patient who underwent CT was a candidate for IV-tPA on the MSTU but could not be evaluated because of video failure. This patient was brought to the nearest ED and was administered IV-tPA conventionally after review of the portable CT images.

**Process Time on the MSTU**

One hundred patients on the MSTU and 56 comparison patients evaluated in the EDs were similar in age and stroke severity (Table 1). On the MSTU, the median door to CT completion time was 13 minutes (IQR, 9–21 minutes), the median door to CT read time was 25 minutes (IQR, 20–29 minutes), the median door to international normalized ratio result time was 13 minutes (IQR, 7–18 minutes), and the median door to intravenous thrombolysis time was 32 minutes (IQR, 24–47 minutes). The median door to CT completion time, door to international normalized ratio result time, and time to IV-tPA administration were shorter in the MSTU group. For the 16 patients who received intravenous thrombolysis, the time to thrombolysis was reduced by 26 minutes compared with ED controls (32 vs 58 minutes, *P* < .001). The median times from the door to CT read were similar in both groups at 25 minutes (P = .59). Table 1 also lists various transport times associated with MSTU activation and dispatch.

**Discussion**

We present our initial field experience using a dedicated prehospital stroke ambulance and treatment delivery system equipped with telemedicine. The usefulness of mobile stroke unit care in shortening the time to thrombolysis has been demonstrated recently in Europe; however, these studies were designed with the need for an on-site neurologist. We demonstrate successful incorporation of telemedicine into the MSTU in Cleveland, rendering the presence of a physician on the mobile unit unnecessary. During the first 3½ months of service, the MSTU managed and transported 100 patients who had initial symptoms suspicious of stroke based on the emergency call intake. The MSTU was able to approach all neighborhoods of Cleveland, and patient race/ethnicity characteristics matched closely with the city statistics. Most assessments by the city EMS before transferring the patient into the MSTU were short. Using telecommunication, we were able to ensure safe and timely transfer of patients based on their geographic location.

The use of telemedicine in stroke care is not new, and its usefulness in prehospital stroke evaluation and triage has been explored in several feasibility studies. More so than the concept of mobile stroke units was introduced in 2003 by Fassbender et al. However, most of these investigations were conceptual studies and used simulated scenarios. A pilot study assessing telemedicine feasibility in a prehospital setting in Aachen, Germany, showed that such a system is feasible but faced connectivity telemedicine issues and delayed door to imaging times. Improvement of wireless network communication over the last few years has allowed transmission of high-quality video data over cellular networks. In our initial phase, telemedicine in the MSTU was highly successful. The VN was available via video at the time of the patient’s entry into the MSTU but per our protocol waited for the CT to be completed before logging in by video. This wait was reflected in the median door to video log-in time of 11 minutes. This time was also spent constructively by

<table>
<thead>
<tr>
<th>Variable</th>
<th>MSTU (n = 100)</th>
<th>Controls (n = 56)</th>
<th><em>P</em> Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, median (IQR), y</td>
<td>62 (53–76)</td>
<td>64 (57–79)</td>
<td>.22</td>
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<tr>
<td>Female sex, No. (%)</td>
<td>54 (54.0)</td>
<td>32 (57.1)</td>
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<td>Race/ethnicity, No. (%)</td>
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<td>9 (16.1)</td>
<td>.12</td>
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<tr>
<td>Other</td>
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<td>7 (12.5)</td>
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<td>Initial National Institutes of Health Stroke Scale score, median (IQR)*</td>
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<td>6.5 (2–13)</td>
<td>.70</td>
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<td>IV-tPA, No. (%)</td>
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<td>13 (23.2)</td>
<td>.30</td>
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<td>Process time, median (IQR), min</td>
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<td></td>
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<td>MSTU activation to scene arrival</td>
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<td>On-scene time until entry into the MSTU&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>Door to CT completion</td>
<td>13 (9–21)</td>
<td>18 (12–26)</td>
<td>.003</td>
</tr>
<tr>
<td>Door to CT read</td>
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<td>25 (19–35)</td>
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<td>Door to international normalized ratio result</td>
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<td>44 (36–61)</td>
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<td>Door to IV-tPA</td>
<td>32 (24–47)</td>
<td>58 (53–68)</td>
<td>&lt;.001</td>
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<tr>
<td>Door to video log-in</td>
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<td>NA</td>
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<tr>
<td>Video duration</td>
<td>20 (14–27)</td>
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<td>NA</td>
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<td>Total MSTU use from activation until arrival at destination hospital per episode</td>
<td>86 (78–93)</td>
<td>NA</td>
<td>NA</td>
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</tbody>
</table>

Abbreviations: CT, computed tomography; IQR, interquartile range; IV-tPA, intravenous tissue plasminogen activator; MSTU, mobile stroke treatment unit; NA, not applicable.

*<sup>a</sup> Measured in the MSTU via telemedicine.

<sup><sup>a</sup>Defined as the time spent by the crew at the site before transfer into the MSTU.</sup>

**Table 1. Patient Characteristics and Evaluation Process Times**
the physician using the medical record to check for any pertinent history if available. Only 6.0% (6 of 100) of our telemedicine evaluations encountered technical difficulties (Table 2), most due to pockets of poor network reception. This result was compared with a feasibility study by Wu et al using a fourth-generation (4G)/long-term evolution network, which encountered an 85% success rate in 40 simulated scenarios in Houston, Texas, as well as a 98% success rate by Van Hooff et al, who used a 3G network in Brussels, Belgium. In the latter study, the screen resolution had to be reduced to ensure undisturbed video streaming. In our evaluation, when faced with a technical disruption, the encounter was instantly switched to a regular telephone call until the physician was reconnected by video. In 2 of the network failures, the connection was restored after the ambulance moved 3 m in the direction of a stronger signal. None of our delays lasted longer than 1 minute, and there was no effect on patient care. Even in cases of technical delay or difficulty, factors responsible were identified and corrected immediately if possible. In the single instance when a telemedicine connection could not be established, having the specialized crew with significant stroke experience on board aided in rapid treatment on arrival at the receiving hospital. Based on the crew’s evaluation and review of the portable CT, a quick confirmatory examination was performed, and IV-tPA was administered rapidly.

We were able to complete CT in almost all patients, except for one instance when the patient required advanced cardiac life support. The onboard CT system had no technical difficulties or power breakdowns. Some delays in obtaining CT were related to patient characteristics such as excessive agitation or medical optimization. Except for 2 instances, CT transmission to a radiologist was rapid, and the CT was read within a median of 12 minutes from completion, resulting in the same time to CT reading as in the ED. The CT was also available to view rapidly at the VN workstation, and a preliminary decision on IV-tPA administration could be made.

To demonstrate feasibility, we hypothesized that the process times from when the patient entered the door of the MSTU should be similar or shorter compared with ED controls. The MSTU process times met the in-hospital time targets to CT and thrombolysis. Our data demonstrated that the evaluation and treatment were not only comparable to ED times but also shorter in terms of CT, laboratory processing, and thrombolytic administration. Intravenous thrombolysis was successfully administered to 48.5% (16 of 33) of patients with suspected stroke and was delivered quickly in the MSTU. The shortest time from the door to IV-tPA administration was 11 minutes, which highlights the potential application of MSTUs in delivering early thrombolysis to patients with stroke thereby reducing disability.

While studies have modeled mobile stroke units to be cost-effective from the societal perspective, our investigation implies further reduction in operational costs of MSTUs. Obitivating the need for an on-site neurologist and neuroradiologist would allow multiple mobile units to be operated under a single physician or units to be operated that are graphically distant from the physician. However, our results should be interpreted in light of some limitations. The small sample size of this study does not demonstrate proof of safety. Also, the absence of data on 217 canceled dispatches may introduce ascertainment bias. Only 33.0% (33 of 100) of the evaluations were initially deemed to represent acute ischemic stroke, but the MSTU protocol was created with high sensitivity for evaluation on the MSTU rather than high specificity for stroke. Further studies should investigate the characteristics of patients who are missed by the screening process and demonstrate whether screening methods can be optimized. A larger study in Berlin, Germany, similarly reported that 30.3% (614 of 2027) of deployments were for patients with ischemic stroke. Our control group comprised only one hospital system with 9 hospitals because we did not have access to patient data from other hospitals in Cleveland. However, using rigorous inclusion criteria and restricting our analysis to only the City of Cleveland EMS, we believe that this control group represents the typical stroke population of Cleveland.

Conclusions

It is feasible to perform prehospital stroke evaluation and treatment using a telemedicine-enabled MSTU. The system would allow a physician to cover multiple MSTUs and broaden the geographic coverage, rendering the concept more efficient and cost-effective.


