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ORIGINAL ARTICLE

Telemedicine-Enabled Ambulances for Prehospital Acute Stroke Management: A Pilot Study

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Abstract

Objective: To assess the feasibility and potential scalability of telemedicine-enabled ambulances for the prehospital evaluation of patients with suspected acute stroke symptoms.

Patients and Methods: A pilot study of telemedicine-enabled ambulances for evaluating patients with suspected acute stroke symptoms en route at 2 tertiary academic comprehensive stroke centers from January 1, 2018, to February 5, 2024. Charts of included patients were reviewed for demographic data, vascular risk factors, final diagnosis, time from arrival to neuroimaging, door-to–needle and door-to-puncture times in patients eligible for acute treatment, and any reported technical challenges during audio-video consultations.

Results: Forty-seven patients (mean age, 68.0 years; 62% men) were evaluated via telemedicine-enabled ambulances, of which 35 (74%) where for hospital-to-hospital transferred patients. Mean time from arrival to neuroimaging was 11.8 minutes. Twenty-nine patients (62%) were diagnosed with acute ischemic stroke, and the remainder were diagnosed with intracranial hemorrhage (n=13), seizure (n=2), brain mass (n=1), or other diagnoses (n=3). Four patients (9%) received intravenous thrombolysis with alteplase (mean door to needle, 30.3 minutes), and 15 patients (32%) underwent mechanical thrombectomy (mean door to puncture, 72 minutes). Technical challenges were reported in 15 of the 42 (36%) cases, of which 10 (67%) were related to poor internet connectivity.

Conclusion: Telemedicine-enabled ambulances in emergency medical services systems are novel, feasible, and potentially scalable options for evaluating patients with suspected acute stroke in the prehospital setting. However, optimization of infrastructure, staffing models, and internet connectivity is necessary, and larger studies evaluating the clinical and cost effectiveness of this approach are needed before widespread implementation.

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Ischemic stroke is a leading cause of death and disability in the United States and worldwide.[1,2] Improved access to time-sensitive treatments for acute ischemic stroke (AIS) including intravenous thrombolysis and mechanical thrombectomy has led to more favorable outcomes for these patients.[3,4] Unfortunately, fewer than 10% of potentially eligible patients with AIS receive this treatment, as many patients presenting outside the time window for such therapy.[5]

Given the time-sensitive nature of AIS treatment, effective prehospital stroke recognition and management is critical to help improve outcomes. In the last few years, there has been increasing evidence demonstrating improved outcomes in patients treated in mobile stroke units (MSUs), specialized ambulances equipped with personnel, telemedicine equipment, and imaging capabilities to diagnose and treat stroke in the prehospital setting.[6,7] Despite this evidence, the MSU model has failed to expand beyond select high-volume academic centers largely because of high costs, poor reimbursement, and logistical challenges.[8] Therefore, a greater emphasis to enhance traditional emergency medical services (EMS) is still paramount to improve acute stroke systems of care. One approach involves the incorporation of telemedicine in existing ambulances to connect patients and EMS personnel with a remotely located neurologist, especially in resource-constrained environments. Although telemedicine-enabled ambulances do not afford the opportunity for prehospital treatment with intravenous thrombolysis, their use allows real-time audio-video consultation with stroke experts who can evaluate and diagnose patients before hospital arrival, which in turn can improve triage and expedite in-hospital treatment. This strategy may overcome some of the perceived MSU limitations while facilitating both enhanced prehospital stroke management and faster in-hospital treatment.

Currently, the literature pertaining to the feasibility and impact of telemedicine-enabled ambulances for prehospital acute stroke treatment is scarce. Thus, in this pilot study, we aimed to describe the early experience with this approach at 2 tertiary urban academic hospitals to highlight current challenges, discuss future considerations, and make estimations of scalability for this novel model.

PATIENTS AND METHODS

Study Design and Patient Population

This pilot study enrolled consecutive patients with suspected acute stroke transferred by EMS to 2 tertiary urban academic comprehensive stroke centers at Mayo Clinic Hospital in Jacksonville, FL, and Mayo Clinic Hospital in Phoenix, AZ, who underwent prehospital telemedicine evaluation by on-call vascular neurologists from January 1, 2018, to February 5, 2024. Enrolled patients were recorded into pre-existing telemedicine databases, and subsequently, these telemedicine databases and the patients' electronic medical records were reviewed. Chart review included demographic data (age, gender, and ethnicity), vascular risk factors (hypertension, hyperlipidemia, diabetes mellitus, coronary artery disease, heart failure, atrial fibrillation, peripheral arterial disease, obstructive sleep apnea, chronic kidney disease, tobacco use, illicit drug use, and hypercoagulable disorders), initial location before EMS transfer (field or another health care facility), initial National Institutes of Health Stroke Scale score (range from 0-42, with higher values indicating a greater neurological deficit), time from emergency department arrival to neuroimaging with computed tomography (CT) in minutes, initial and final diagnoses, and treatment metrics including door-to-needle (DTN) time for thrombolytic therapy, door-to-puncture (DTP) time for mechanical thrombectomy, and functional outcomes at 90 days as assessed by modified Rankin scale (mRS) (which ranges from 0 [no symptoms] to 6 [death]) whenever available. In addition, telemedicine database were reviewed for any technical or logistical challenges reported by vascular neurologists during prehospital telemedicine encounters (ie, patient no longer in the ambulance, connection to the wrong ambulance, disturbed audio connection, disturbed video connection, disturbed audio and video connection, or poor internet connectivity). Of note, vascular neurologists evaluating this cohort had to immediately answer questions included in the telemedicine databases about any technical issues encountered during their prehospital telemedicine assessment of patients.

Technology and Prehospital Assessment

Teladoc RXpress devices (Formerly InTouch Health, now Teladoc) were installed into selected EMS ambulances, with 5 Teladoc devices placed in 5 ambulances in Jacksonville (2 in partnership with Century Ambulance Services and 3 in partnership with St Johns County Fire Rescue) and connected to Mayo Clinic vascular neurology team in 2018, and 1 Teladoc device was placed in an ambulance in Rio Verde Fire Department EMS in 2020 and connected to Mayo Clinic Arizona vascular neurology team. Emergency medical services personnel were trained how to use the equipment and instructed to consider requesting prehospital telestroke evaluation if they encountered patients with suspected acute stroke symptoms while using one of these ambulances. Prehospital communication leveraged existing prehospital advanced notification system at these facilities, allowing available on-call vascular neurologists to connect remotely to the Teladoc device and initiate prehospital evaluation (Figure 1).

Statistical Analyses

We described and summarized demographic and baseline clinical characteristics for the entire cohort using frequencies, percentages, means, SDs, medians, or interquartile ranges as deemed appropriate.

Ethics

The institutional review board at Mayo Clinic reviewed and approved the study (institutional review board protocol number 22-001955). Enrolled patients or their legal representatives provided informed consent for this study whenever applicable.

RESULTS

A total of 47 patients underwent telestroke evaluation in a telemedicine-enabled ambulance. Five patients arrived at the hospital before the vascular neurologist was able to conduct the encounter. A total of 42 patients underwent complete prehospital telemedicine encounters.

FIGURE 1. Telestroke-enabled ambulance and prehospital telestroke assessment. A patient with suspected acute stroke syndrome being transferred by emergency medical services via a telemedicine-enabled ambulance with audio-video system allowing a vascular neurologist at the receiving facility to evaluate the patient en route. Reproduced with permission. Harahsheh et al, Curr Treat Options Neurol (2022) 24:589-603.

Baseline Characteristics

Of the 47 patients, 62% were men with mean age of 68.0 years (SD, ±14.2 years), and most of them were White (72%). Risk factors included hypertension (83%), hyperlipidemia (79%), diabetes mellitus (30%), coronary artery disease (28%), or a history of stroke or transient ischemic attack (36%) (Table 1). Median National Institutes of Health Stroke Scale score for these patients was 9.5 (interquartile range, 2-19.75).

Prehospital Telemedicine Evaluation

Forty-three patients (91%) were evaluated at the Mayo Clinic in Florida and 4 patients at the Mayo Clinic in Arizona (9%). Initial location for EMS dispatch included both field-to-hospital (F2H) (n=12, 26%) and hospital-to-hospital (H2H) transfers (n=35, 74%) (Table 1). Of note, for patients transferred from H2H, the accepting vascular neurologist was initially notified about these patients via telephone call from the transferring facility. Despite early utilization, the COVID-19 pandemic led to reduction in activations: 39 evaluations (83%) occurred before COVID-19 pandemic, whereas only 8 encounters (17%) occurred during or after the pandemic: 2018, n=8; 2019, n=27; 2020, n=7; 2021, n=1; 2022, n=3; 2023, n=0; and 2024, n=1. Technical and logistical challenges were reported by on-call vascular neurologists in 15 of 42 conducted encounters (36%), of which most were related to poor internet connectivity in the ambulance (n=10, 67%) (Table 2).

Initial and Final Diagnoses, Treatment, and Outcomes

Acute ischemic stroke was the most common final diagnosis in these patients accounting for 62% of cases (n=29), whereas the remaining 18 cases were intracranial hemorrhage or stroke mimics (38%) (Table 3). For H2H, the suspected initial diagnosis by the referring facility was accurate in all but 3 cases (1 patient diagnosed with AIS found to be in status epilepticus, other diagnosed with brain abscess found to have brain tumor, and third diagnosed with intracranial aneurysm found to have isolated oculomotor nerve palsy, and the rest had initial diagnosis of either AIS or intracranial hemorrhage, which were similar to final diagnosis). For F2F cases, the vascular neurologists evaluating these patients in the prehospital setting suspected acute stroke syndrome in all but 2 patients (1 seizure and other one recrudescence of previous neurologic deficits), and the final diagnosis was AIS in 11 and intracerebral hemorrhage in 1. Mean time from arrival to neuroimaging with CT head was 11.8 minutes. Four patients (9%) received thrombolytic therapy with a

TABLE 1. Baseline Characteristics, Final Diagnoses, and Telemedicine Challenges

Variable	No. of patients (N=47), n (%)
Age (y), mean (SD)	68.0 (±14.6)
Gender	
Male	29 (61.7)
Female	18 (38.3)
Ethnicity	
White	34 (72)
African American	6 (13)
Hispanic	3 (6)
Others	4 (9)
Vascular risk factors	
Hypertension	39 (83)
Hyperlipidemia	37 (79)
Diabetes	14 (30)
Coronary artery disease	13 (28)
Heart failure	7 (15)
Atrial fibrillation	18 (38)
Peripheral arterial disease	5 (11)
Obstructive sleep apnea	7 (15)
Previous ischemic stroke/TIA	17 (36)
Previous ICH	5 (11)
Smoking history	31 (66)
H to H or F to H transfer	
H to H	35 (74)
F to H	12 (26)
Date of evaluation	
Pre—COVID-19 pandemic	39 (83)
During/after COVID-19 pandemic	8 (17)
NIHSS, median (IQR)	9.5 (2-19.75)
Door to CT imaging (min), mean	11.8
Patients' final diagnoses	
AIS	29 (62)
Stroke mimic	18 (38)
Thromblytic therapy administration	4 (9)
Door-to-needle time for thrombolytic therapy (min), mean	30.3
Mechanical thrombectomy	15 (32)
Door to groin time for mechanical thrombectomy (min), mean	72
Discharge outcome (n=43)	
Home	20 (47)
Rehabilitation	12 (28)
Skilled nursing facility	6 (14)
Hospice	4 (9)
Death	1 (2)
mRS at 90 d (n=28)	
0-2	10 (36)
3-4	10 (36)
5-6	8 (28)

Continued on next column

TABLE 1. Continued

AIS, acute ischemic stroke; COVID-19, coronarvirus disease 2019; CT, computed tomography; F, field; H, hospital; IQR, interquartile range; mRS, modified Rankin scale; NIHSS, National Institute of Health Stroke Scale.

mean DTN time of 30.3 minutes, 15 patients (32%) underwent mechanical thrombectomy with a mean DTP time of 72 minutes, and of the 4 patients who received thrombolytic therapy, 3 (6%) underwent mechanical thrombectomy as well. As a comparison, for patients presenting to the emergency department at Mayo Clinic Florida for suspected acute stroke syndromes over 4-year period (2020-2023), the site with the highest number of telemedicine-assessed patients in this cohort, mean DTN time in minutes was 46, 47, 44, and 42 for the years 2020, 2021, 2022, and 2023, respectively. In addition, mean DTP time for patients transferred F2H during the same period was 81.7, 83.2, 66.1, and 70.5 minutes, respectively. On the contrary, mean DTP time for patients transferred H2H during the same period was 72.0, 63.3, 56.5, and 51.7 minutes, respectively. In addition, the mean door to imaging time in minutes for patients transferred F2H was 21.5, 24.9, 24.3, and 33.0, respectively, and for patients transferred H2H, it was 18.1, 24.7, 18.7, and 18.6 for the same period (2020-2023). At discharge, 20 of the 46 patients (47%) were discharged home, 12 of the 46 patients (28%) discharged to inpatient rehabilitation units, and 4 of the 46 (9%) patients transitioned to hospice. Of the 29 patients with documented mRS at 90 days, 10 (36%) achieved favorable functional outcome with mRS of 0-2.

DISCUSSION

Our pilot study described an early experience leveraging telemedicine-enabled ambulances

TABLE 2. Encountered Technical Challenges During Prehospital Telemedicine Evaluation of Patients With Acute Stroke Symptoms

Technical challenge	Total number (n=15 of 42 conducted encounters), n (%)
Poor internet connectivity	10 (67)
Audio connection	2 (13)
Video connection	1 (6.7)
Audio and video connection	1 (6.7)
Connection to wrong ambulance	1 (6.7)

to conduct prehospital telestroke evaluation at 2 urban tertiary academic comprehensive stroke centers and yielded several important findings. First, prehospital evaluation of patients with suspected acute stroke syndromes is feasible as vascular neurologists in our study were able to evaluate patients en route in almost all encounters despite limited technical challenges. Second, prehospital assessment can be potentially effective as door to imaging, DTN, and DTP times for eligible patients in this small cohort were acceptable and in accordance with get with the guidelines recommendations. Third, our results suggest potential areas for improvement and optimization of this model because the utilization of telemedicine-enabled ambulances has remarkably decreased during and after COVID-19 pandemic at our tertiary academic centers, poor internet connectivity was a limiting factor

TABLE 3. Final Diagnosis of Patients With Acute Stroke Symptoms Evaluated in the Prehospital Setting via Telemedicine-Enabled Ambulances

Final diagnosis	n (%)
Acute ischemic stroke	29 (62)
Intracranial hemorrhage[a]	13 (28)
Seizure	2 (4)
Brain mass	1 (2)
Cortical vein thrombosis[a]	1 (2)
Unruptured intracranial aneurysm	1 (2)
Oculomotor nerve palsy	1 (2)

[a]One patient had concomitant intracranial hemorrhage and cortical vein thrombosis.

for optimal assessment and evaluation of patients in the prehospital setting, and most of the conducted encounters were for H2H transfers, where diagnosis is often established, rather than F2H transfers.

Current prehospital stroke assessment relies heavily on paramedic-applied stroke scales for diagnosis and triage of patients to appropriate stroke centers. For example, multiple EMS-administered prehospital large vessel occlusion (LVO) scales[9–12] are available to help EMS personnel screen patients with acute stroke symptoms for possible LVO and subsequent triage to appropriate comprehensive stroke centers or thrombectomy-capable stroke centers. However, these scales have limited diagnostic accuracy for LVO[13] and are operator dependent because they rely on the skills of paramedics for administration and interpretation, which can limit their utility and overall accuracy in the prehospital setting. Moreover, MSUs have been used over the last decade for prehospital stroke management with multiple studies and several major clinical trials[6,14–17] demonstrating the impact of this model on increasing patients' access to hyperacute stroke therapy, expediting the delivery of thrombolysis to patients with AIS, triaging patients to appropriate stroke centers, improving patients' functional outcomes, and providing socioeconomic benefits for implementation in certain urban areas, especially in countries with more socialized medicine and health care systems.[18] However, despite clear mounting evidence supporting MSU use for prehospital stroke management, many factors have limited the widespread acceptance and utilization of this model. First, the MSU is costly with current estimate of 1 million US dollars to build 1 MSU unit, and another $1 million US dollars annually are needed for operational costs for each unit.[19] Second, their utilization for prehospital assessment of nonstroke patients (ie, cardiac and respiratory emergencies or trauma) maybe limited given the MSU design specifically to address patients with suspected acute stroke syndromes, thus limiting their scalability and interoperability to other nonneurologic emergencies. Third, integration of this model into pre-existing EMS infrastructure can be challenging because it requires special large ambulances that include an imaging system with CT scanner, point-of-care laboratory testing, appropriate medications including thrombolytic therapy, telemedicine capability to connect to a remote vascular neurologist, as well as appropriate staffing personnel including radiology technicians and stroke-trained nurses and education; thus, integration can be resource consuming and labor intensive for both EMS and health care facilities.

Our study provides a glimpse at the potential feasibility and scalability of prehospital telemedicine-enabled ambulances, "mini-MSU," as an additional and possible alternative tool to enhance stroke triage, diagnosis, and management. Although this model does not allow administration of thrombolytic therapy in the prehospital setting compared with MSU, it can still enhance stroke recognition, improve triage accuracy to appropriate comprehensive or thrombectomy-capable centers, and facilitate faster in-hospital treatment through prehospital resource mobilization.[20,21] Moreover, this model can overcome some of the limitations of MSU that limited its widespread use and utilization (Figure 2). First, the estimated initial ($2000-$25,000 per unit) and recurring costs ($6000 per unit) with this model are much less compared with those of MSU-related expenses.[8] Second, this model can be integrated at substantially reduced cost into pre-existing EMS infrastructure and ambulances without the need for special ambulances, imaging equipment, or more staffing personnel because it mainly requires installation of audio-video telemedicine equipment in the ambulances and good internet connectivity with the receiving facilities where vascular neurologist can evaluate patients en route and uses pre-existing paramedic staffing models without the need for additional personnel. Third, telemedicine-enabled ambulances can be used to create extensive network for community coverage and can also be leveraged for prehospital assessment of patients with other nonneurologic emergencies (ie, acute coronary syndromes, acute respiratory distress, and trauma), thus, increasing its potential scalability and interoperability to other specialties beyond neurology, which may not be easily feasible for MSU. Multiple previous published studies found the feasibility and effectiveness of this mini-MSU model for implementation in prehospital settings.[21−23] For example, a 2-center study in the United States using a low-cost, tablet-based mobile telestroke in ambulances to evaluate standardized stroke patients in the prehospital setting using commercial cellular networks for video conferencing reported that prehospital neurologic assessment can be reliably performed without marked technical challenges and with similar accuracy to bedside evaluation.[22] In addition, 2 studies reported that patients with AIS evaluated initially in the prehospital setting using telemedicine-enabled ambulances have shorter DTN times, and 1 study reported shorter DTP times for patients with in-transit telestroke assessments to the emergency department than those for patients without.[21,24]

Despite the increased and promising potential for widespread implementation and utilization of this mini-MSU model for prehospital telestroke assessment, our study suggests several areas for potential improvement and optimization for this model. First, education of EMS personnel are still of paramount importance, especially when and how to activate and request telemedicine evaluation earlier for their patients with suspected acute stroke symptoms because our results found significant decreased utilization of this model during and after the COVID-19 pandemic, which can be partially related to EMS personnel turnover without re-education and re-emphasis about the importance of early telestroke activation en route, previous EMS experiences with poor connectivity during such encounters limiting their perceived usefulness of this technology in this setting, and possible short transport time, especially because 10% of our cohort could not be initially assessed by vascular neurologists as the patients had already arrived the receiving health care facilities by the time vascular neurologists were able to connect, thus leading to overall decreased prehospital telestroke activation and notifications by paramedics. Expanding this model to other nonneurologic emergencies can potentially familiarize EMS personnel with the use and request of telemedicine activations, especially because only 2% of current EMS dispatches in the United States are related to patients with stroke,[25] thus encouraging more prehospital telestroke activations. Second, technical and logistical challenges are

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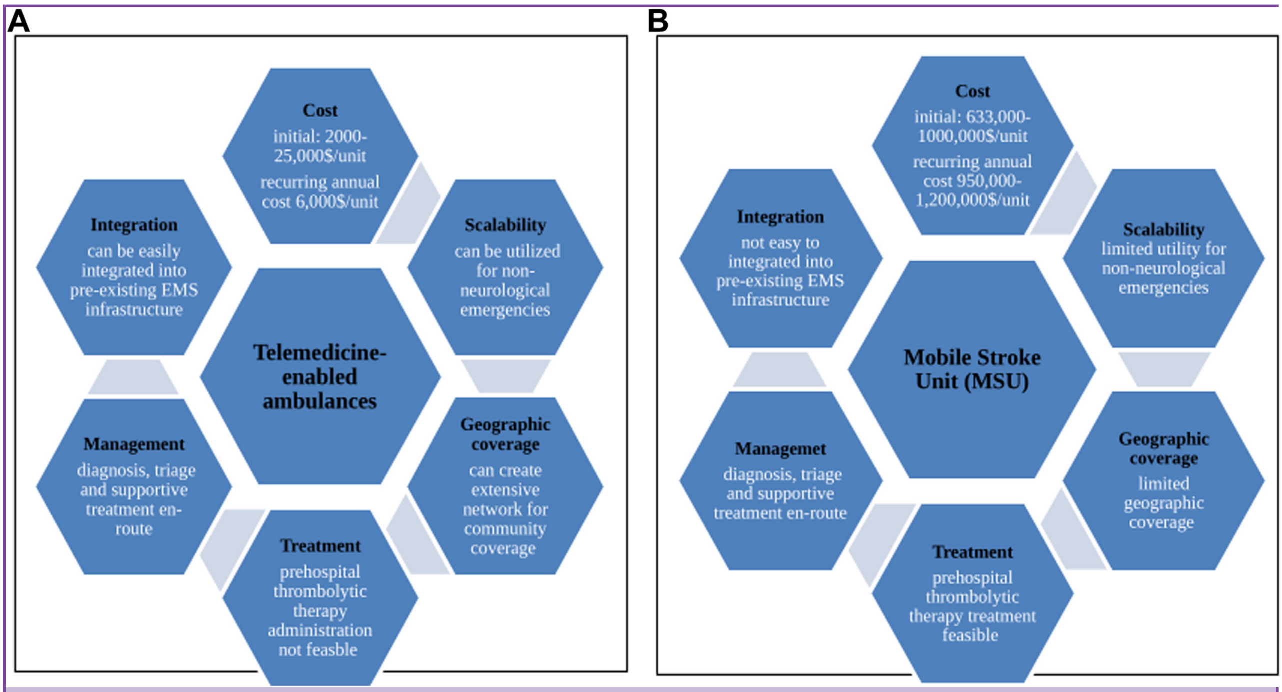

FIGURE 2. Comparison of telemedicine-enabled ambulances and mobile stroke units models for prehospital telestroke management.

not uncommon when evaluating patients in the prehospital setting using this model, predominantly due to poor internet connectivity, which could be partially related to variable geographic internet coverage. Therefore, establishing good infrastructure within the targeted geographic areas including having good and reliable internet coverage, preferably 5G, and collaboration between local authorities, EMS services and health care facilities are essential key factors for the success and widespread implementation of this model. Nevertheless, leveraging audio connection only, if needed, for prehospital telestroke assessment can be used in geographic areas with poor internet access or connectivity because audio connection can still provide some pertinent information and guide management and triage process. Finally, if further optimization of this Teladoc model is not feasible, using alternative models such as iPAD-based assessment can be considered to overcome some of the real-life challenges especially because less technical challenges were reported with this model.[22]

Our study has several limitations. First, the descriptive nature of the study, small number of available telemedicine-enabled ambulances, the significant decrease in utilization during and after COVID-19 pandemic, and the overall small sample size of patients assessed via this modality would preclude any major inferences or conclusions. The major reasons for the unexpected significant decrease in the utilization and activation of this model during and after the pandemic in the years 2021-2024 were related to the high-turnover rate of EMS personnel, which made reliable and consistent education to use this approach for prehospital evaluation of patients with suspected acute stroke syndromes challenging. In addition, financial constraints on this project invoked by the pandemic impacted the sustainability, not to mention the growth and expansion of this project. Second, most of the patients assessed in the prehospital setting were transferred from other health care facilities (74%) rather than directly from the field (26%) for higher level of care, mainly to assess patients' eligibility for endovascular intervention, because some of these patients were already known to have possible LVO. However, proportions of patients receiving mechanical thrombectomy were not remarkably different among patients transferred from the field (45%) or those transferred from other health care facilities (55%). Fourth, the lack of control sample of patients transported with suspected acute stroke syndromes not evaluated by telemedicine in the prehospital setting preclude any possible comparisons of this model with standard of care of immediate evaluation of these patients in the emergency department either in-person or via telestroke in improving DTN or DTP times for patients eligible for acute treatment. However, our reported mean DTN and DTP times are acceptable per current get with the guidelines recommendations and more favorable compared with the DTN and DTP times in the 4-year period (2020-2023) at Mayo Clinic Florida where 90% of the cohort were enrolled.

CONCLUSION

Telemedicine-enabled ambulances in EMS systems are novel, feasible, and potentially scalable option for evaluating patients with suspected acute stroke syndromes in the prehospital setting. However, optimization of infrastructure, ensuring seamless wireless internet connectivity, and larger prospective studies and randomized clinical trials evaluating the clinical and cost effectiveness of this approach are needed to assess real-world challenges and increase widespread implementation and utilization of this novel model.

POTENTIAL COMPETING INTERESTS

The authors report no competing interests.

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Abbreviations and Acronyms: **AIS,** acute ischemic stroke; **CT,** computed tomography; **DTN,** door to needle; **DTP,** door to puncture; **EMS,** emergency medical services; **MSU,** mobile stroke unit; **mRS,** modified Rankin scale

Ethics Statement: The institutional review board at Mayo Clinic reviewed and approved the study (institutional review board protocol number 22-001955). Enrolled patients or their legal representatives provided informed consent for this study whenever applicable.

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