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Review

Review of the Mobile Stroke Unit Experience Worldwide

Victoria J. Calderon[a] Brittany M. Kasturiarachi[b] Eugene Lin[a]
Vibhav Bansal[c] Osama O. Zaidat[a]

[a]Mercy Health-St. Vincent Medical Center, Toledo, OH, USA; [b]Ohio University Heritage College of Osteopathic Medicine, Athens, OH, USA; [c]Mercy Health-St. Rita Medical Center, Lima, OH, USA

Keywords
Emergency medical services · Mobile stroke unit · Prehospital stroke treatment · Stroke management · Thrombolysis

Abstract
Background: The treatment of stroke is dependent on a narrow therapeutic time window that requires interventions to be emergently pursued. Despite recent "FAST" initiatives that have underscored "time is brain," many patients still fail to present within the narrow time window to receive maximum treatment benefit from advanced stroke therapies, including recombinant tissue plasminogen activator (tPA) and mechanical thrombectomy. The convergence of emergency medical services, telemedicine, and mobile technology, including transportable computed tomography scanners, has presented a unique opportunity to advance patient stroke care in the prehospital field by shortening time to hyperacute stroke treatment with a mobile stroke unit (MSU). ***Summary:*** In this review, we provide a look at the evolution of the MSU into its current status as well as future directions. Our summary statement includes historical and implementation information, economic cost, and published clinical outcome and time metrics, including the utilization rate of thrombolysis. ***Key Messages:*** Initially hypothesized in 2003, the first MSUs were launched in Germany and adopted worldwide in acute, prehospital stroke management. These specialized ambulances have made the diagnosis and

V.J. Calderon and B.M. Kasturiarachi contributed equally to this work.

Osama O. Zaidat, MD, MS, FAAN, FAHA
Mercy Health-St. Vincent Medical Center, The Neuroscience Institute
Medical Office Building 2, Suite M200, 2222 Cherry Street
Toledo, OH 43608 (USA)
E-Mail oozaidat@mercy.com

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treatment of many neurological emergencies, in addition to ischemic and hemorrhagic stroke, possible at the emergency site. Providing treatment as early as possible, including within the prehospital phase of stroke management, improves patient outcomes. As MSUs continue to collect data and improve their methods, shortened time metrics are expected, resulting in more patients who will benefit from faster treatment of their acute neurological emergencies in the prehospital field.

Introduction

Stroke is the second leading cause of death worldwide since 2010, accounting for more than 11% of total mortality [1]. In the United States, stroke is the fifth leading cause of death and a major cause of long-term disability [1]. Treatment of stroke is dependent on a narrow therapeutic time window, as human nerve tissue is rapidly and irreversibly lost over time [2]. Early identification of acute ischemic stroke is vital in order to provide timely treatment through thrombolysis, which can improve clinical outcome and reduce resulting complications [2]. The only systemic, acute treatment for stroke that has been proven effective is recombinant tissue plasminogen activator (tPA), but its recommended window of use is within 3–4.5 h from stroke symptom onset [3, 4]. The efficacy of intravenous (IV) thrombolysis is a function of time; the earlier a patient is treated, the greater the likelihood he or she will have a good recovery [5]. Despite this knowledge, patients often arrive at a hospital too late to receive maximum treatment benefit from advanced stroke therapies; delay in hospital represents a major barrier to medical treatment [6–8]. The median time from symptom onset to a patient's hospital admission is between 3.5 and 14 h, although it is difficult to directly compare studies with different designs [7–15]. As such, less than 5% of stroke patients are treated by thrombolysis, even in centers specialized for stroke [16].

Thrombolysis for ischemic stroke can only be performed after the possibility of a hemorrhage has been excluded by computed tomography (CT) imaging, and a CT scan without contrast is recommended in patients who have a suspected stroke within a 3–4.5 h time period [17, 18]. Since not all hospitals are able to provide CT scans 24 h per day, important time is lost transporting patients to CT-capable centers [17]. The convergence of emergency medical services (EMS), telemedicine, and mobile technology, including transportable CT scanners, has presented a unique opportunity to advance patient stroke care in the prehospital field by circumventing delay to hyperacute stroke treatment with a mobile stroke unit (MSU) [19].

A MSU, also known as a stroke emergency mobile (STEMO) or mobile stroke treatment unit (MSTU), combines a specially trained team, conventional emergency equipment, telemedicine capabilities, a CT scanner, and diagnostic tools used to make an emergent decision for or against thrombolysis directly at the place where a patient is found (Fig. 1) [17]. This provides physicians the information and resources necessary to safely screen patients for IV tPA eligibility and initiate thrombolysis in the field, markedly curtailing symptom onset to treatment times by advancing acute stroke care in the prehospital field [17]. Hyperacute stroke workup at the scene can avoid transport delays, streamline procedures, and provide a highly specialized team ready for acute stroke diagnosis and treatment; implementation of these advances may lead to earlier stroke identification and shorten time to therapy [17, 19]. In this review, we provide a look at the evolution of the MSU into its current status, as well as future directions, through historical and implementation information, economic cost, and published clinical outcome and time metrics.

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Fig. 1. a A mobile stroke unit ambulance built by Frazer. **b** Mercy Health Mobile Stroke Unit.

Methods

A literature search was conducted using PubMed and Google Scholar. A literature retrieval with assistance from Mercy Regional Library Services was also utilized. The key words used to search the stroke literature between 1990 and 2017 included "mobile stroke," "MSU," "mobile stroke unit," "telemedicine," "emergency medical services," "prehospital phase," "stroke management," and "thrombolysis." The references of identified articles were also reviewed for any MSU-related research. Internet search engines, such as Google, were also used to search for pages that might provide relevant references. Articles were selected on the basis of their relevance to the topic of MSUs and prehospital stroke management. Our search was restricted to reports in English. Thirty-eight papers were chosen for this review.

Results

History of the MSU

In 2003, Fassbender et al. [17] proposed the idea of a mobile unit for hyperacute stroke treatment to address the delay between stroke symptom onset, or last known well (LKW), and therapeutic intervention, to save important time lost by patient transfer to and within a

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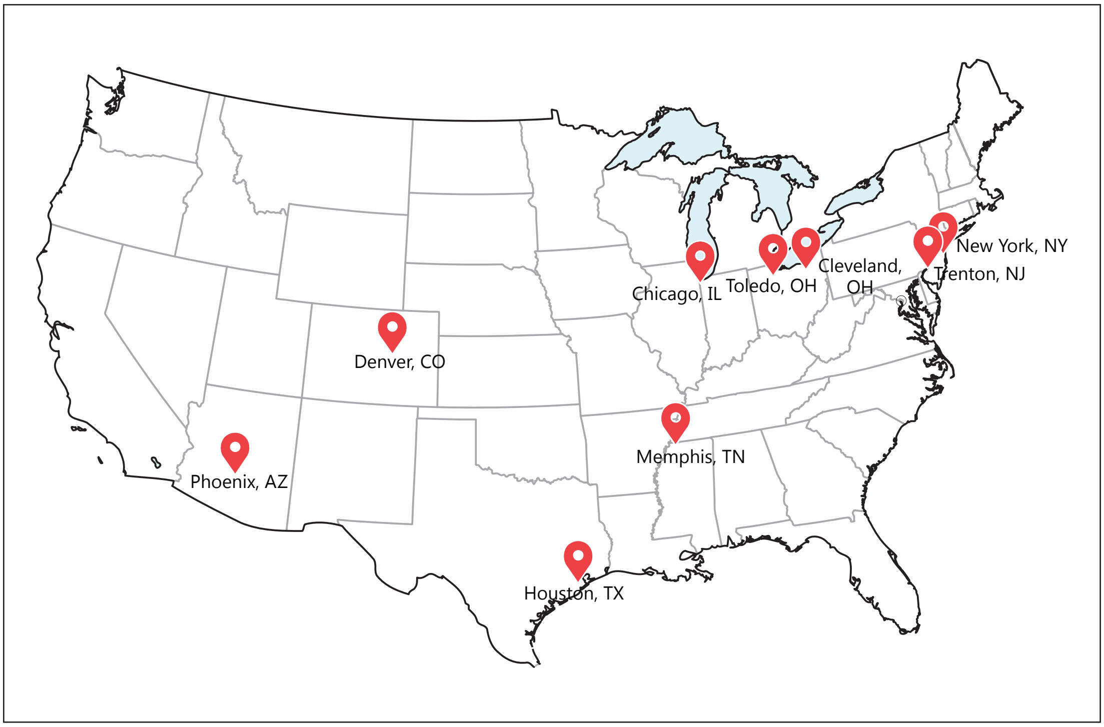

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Fig. 2. Map of mobile stroke units launched by June 2017 in the United States.

hospital. Unlike a stationary stroke unit, the hypothesized MSU vehicle could carry diagnostic tools used to decide for or against thrombolysis at the site, in addition to conventional emergency equipment. At the time, this idea required unique technical innovations, all of which needed to remain within the normal limits of emergency vehicle dimensions, including a small, integrated CT scanner with an operation console and energy supply, a CT radiation shield, an optional laboratory unit, and a system to transmit CT information [17].

Beginning in 2009, a randomized clinical trial by the Saarland University Hospital in Homburg, Germany evaluated the feasibility of this prehospital healthcare delivery system [20]. The first MSU, or "stroke ambulance," was successfully founded in 2010 in Homburg, Germany after a year of preparation [21]. The specialized ambulance, in addition to its conventional equipment, was outfitted with an accumulator-driven, lead-shielded CT, a telemedicine system, and a point-of-care laboratory system [20]. These components, which are necessary for making therapeutic decisions, still comprise modern MSUs.

Guideline-adherent and etiology-specific treatments for ischemic and hemorrhagic strokes in the prehospital phase of stroke management were demonstrated by two MSU cases in Homburg [22]. These examples showed that MSUs are capable of more than expediting acute ischemic stroke treatment. They may also use telemedicine to contact hospital experts, manage physiological variables, improve hospital transport decision-making, and facilitate and expedite emergent care for other neurological emergencies [22].

The second MSU was launched in Berlin, Germany in July 2011 [23]. The Pre-Hospital Acute Neurological Therapy and Optimization of Medical Care in Stroke Patients (PHANTOM-S) study compared the MSU, or STEMO, to conventional care [23]. Study weeks were designated to STEMO service or routine care (control) [24]. The PHANTOM-S study concluded that using ambulance-based thrombolysis decreased time to treatment without increasing adverse events; however, more research is necessary to assess MSU effects on patient clinical outcomes [24].

With promising results from Homburg and Berlin, the first MSU in the United States went live in Houston, TX in May 2014 [22]. The Cleveland Clinic followed suit, launching their MSU in July 2014 [25]. The third MSU in the United States was launched in Denver, CO in January 2016. Similar to the MSUs in Germany, these were not operational 24 h a day, 7 days a week. The Mercy Health MSU in Toledo, OH was launched later in January 2016 as the fourth MSU in the country; it remains the only 24/7 MSU in the world. Other additional MSU locations in the United States include Memphis, TN (July 2016), New York, NY (October 2016), Chicago, IL (January 2017), Trenton, NJ (January 2017), and Phoenix, AZ (June 2017) (Fig. 2; Table 1). The number of MSUs worldwide continues to increase every year.

Implementation

Establishing a streamlined integration of MSUs into a conventional, prehospital EMS chain is vital. This requires cooperation from stakeholders in both the prehospital and in-hospital phase, including MSU staff, hospital administrators, EMS personnel, and the community. This multidisciplinary team is integral in seeking funding, purchasing, and building-out the physical MSU, as well as licensing, inspecting, equipping, insuring, and credentialing the vehicle before integrating it with local EMS [26].

MSU staff and local EMS also require training to conduct their roles on the rig, as they have not been previously exposed to CT imaging or the administration of thrombolytics in the field. Follow-up training and feedback from the numerous teams that arrive at the scene to evaluate and treat a patient is needed to improve patient outcomes and develop accountability with a feedback system.

Several MSUs were first launched with a pilot program period to test stakeholder roles and determine important research variables, including expected enrollment rate and patient demographics [21, 22, 24]. These test periods allowed new MSUs to identify potential problems, such as EMS integration or telemedicine connection, as well as areas of growth before resuming regular service.

Personnel

A functioning MSU requires substantial dedicated manpower. For example, the Houston MSU has required employment of a principal investigator, a program manager, and at least two vascular neurologists (VNs), in addition to the EMS personnel staffing the ambulance [22]. These include a critical care nurse, a CT technician, and an EMS provider or paramedic. A VN may also physically travel with the MSU or participate on scene using telemedicine technology. The BEST-MSU study in Houston is determining whether it is advantageous to have a VN on board instead of sole availability through telemedicine, as well the viability of cross-training MSU team members to complete multiple tasks, including cross-training a paramedic as a CT technician [26]. If possible, a future MSU team will include three individuals on board: a paramedic, an emergency medical technician, and a critical care nurse could carry out MSU tasks [26]. A complete list of on-board personnel for specific MSUs can be found in Table 1.

MSUs generally rely on dispatchers from a standard emergency medical system response to identify and alert the MSU of potential strokes. If an EMS team arrives first, the patient will be administered a prehospital scale and the MSU will be mobilized in the appropriate clinical circumstances. Upon arrival, the MSU team assumes care of the patient for further assessment and management, with a decision made regarding triage and drop-off destination.

At the emergency site, the MSU team is responsible for obtaining a patient history, a neurological and laboratory examination, a CT scan (if appropriate), and an evaluation with the remote VN via telemedicine. If eligible, thrombolysis is given onsite.

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Table 1. MSUs launched by June 2017

Location	Began service	On-board personnel	Operating hours	Catchment area
Homburg, Germany	March 2011	UNK	UNK	20 km around the university hospital
Berlin, Germany	July 2011	paramedic, stroke physician, neuroradiologist	UNK	20 km around the university hospital
Fredrikstad, Norway	October 2014	neurologist, paramedic, radiology technician	07:00–11:00 daily, Monday to Sunday, randomized weeks	defined by a 75% probability of reaching the emergency sites within 16 min from base, based on calculations by the Berlin Fire Department
Houston, TX, USA	May 2014	CT technician, VN, RN, paramedic	08:00–18:00 daily, Tuesday morning to Monday evening, 50% weeks	3-mile radius
Cleveland, OH, USA	July 2014	CCN, EMT, paramedic, CT	08:00–20:00 daily	UNK
Buenos Aires, Argentina	October 2014	UNK	UNK	UNK
Denver, CO, USA	January 2016	neurologist[a], CCN, technician, paramedic, EMT	UNK	UNK
Toledo, OH, USA	January 2016	VN[a], critical care transport nurse, critical care transport paramedic, CT technician	24/7	defined as a 15-min drive time radius, but fire departments and EMS can also "special request" the MSU
Memphis, TN, USA	July 2016	stroke fellowship-trained doctorally prepared nurses, Advanced Neurovascular Practitioner board certified	12 h a day, 1 week on, 1 week off	10-mile radius but can be dispatched within the entire city metro area
New York, NY, USA	October 2016	neurologist, 2 paramedics, CT technician	UNK	communities surrounding NY-Presbyterian/Weill Cornell Medical Center/Columbia University Medical Center
Chicago, IL, USA	January 2017	UNK	UNK	communities surrounding Rush Oak Park Hospital that are part of Illinois Region VII
Trenton, NJ, USA	January 2017	UNK	07:00–23:00 daily	Mercer County area
Edmonton, AB, Canada	February 2017	VN[a], 2 paramedics, CT technician	UNK	communities surrounding University of Alberta Hospital
Phoenix, AZ, USA	June 2017	VN and neurologists[a], EMT	UNK	St. Joseph's Hospital and Medical with 20-min response radius

CCN, critical care nurse; CT, computed tomography; EMS, emergency medical services; EMT, emergency medical technician; MSU, mobile stroke unit; RN, registered nurse; UNK, unknown; VN, vascular neurologist. [a] In the unit via telemedicine technology.

Technology and Equipment

The technology necessary to equip a MSU includes a CT scanner, a point-of-care laboratory system, and telemedicine capabilities for contact with hospital staff [20]. The point-of-care laboratory system utilized in the Mercy Health MSU features the iStat machine. This is the standard system for point-of-care laboratories used in the emergency department and is licensed by Mercy Health-St. Vincent Medical Center. During a possible stroke case, a basic metabolic panel is completed. The panel includes serum sodium, potassium, chloride, ionized calcium, total CO_2, glucose, blood urea nitrogen, creatinine, hematocrit, hemoglobin, and the anion gap. The Mercy Health MSU also has the ability to check prothrombin time/international normalized ratio using a CoaguChek machine, although this is usually only done on patients who are known to be on warfarin therapy.

The rising accuracy and reliability of telemedicine has made it an integral part of MSUs. For MSUs that do not have a VN or other specialized personnel on board, telemedicine can offer a way for real-time patient evaluation. Ebinger et al. [24] write that regions that lack enough neurologists may also use telemedicine as a way to provide expertise to the emergency physician or staff on board.

Economics and Billing

Establishing a MSU requires a large financial investment. Two available cost-effectiveness studies suggest that the financial expenditures incurred by MSUs are worthwhile in the long run [27, 28]. Time and economic benefits have been shown to justify specialized ambulances up to an average travel times of 18 min in metropolitan areas [29]. MSU programs have also sought ways of increasing cost-effectiveness in the build-out phase. Parker et al. [22] describe how the Houston MSU used an ambulance design already in use by Houston EMS to help lower startup costs. An emphasis on lowered costs will improve cost-benefit ratios when appealing for MSU coverage by healthcare payers.

In the United States healthcare system, Medicaid and Medicare cover ambulance and other emergency services according to guidelines that define emergent situations. For example, Medicare part B covers ambulance services to the nearest appropriate facility specifically when other modes of transportation could further endanger the patient [30]. Medicaid follows much of the same standards, but will also cover nonemergent rides with a doctor's note [31]. As it is imperative to provide patients with prompt evaluation and treatment in suspected stroke scenarios, MSUs can potentially be covered and reimbursed according to a similar model. If MSUs were covered according to a low-cost model, more patient costs could be covered.

Current Clinical Data and Outcomes

MSUs have been developed to close the gap in time from LKW to treatment. The current state of evidence for prehospital stroke care from a MSU is largely determined by related quality measures, such as time to treatment from symptom onset, emergency site, or hospital door. Less evidence concerning improved functional outcomes in patients treated by MSUs exists at the present time.

The results of the first MSU randomized trial showed that prehospital management achieved a median symptom onset to therapy decision time of 56 min and a median symptom onset to treatment time of 72 min without impaired safety [21]. The number of patients who received therapy within the "golden hour" from LKW also increased significantly from 4% (2 of 42 patients in the control group) to 57% (30 of 54 patients in the MSU group) [21]. The PHANTOM-S study, conducted in Berlin, showed that ambulance-based thrombolysis using a MSU resulted in decreased time to treatment and a ten-fold increase in the rate of "golden hour" thrombolysis versus conventional care [32]. The high rate of "golden hour" throm-

Table 2. Published MSU clinical outcomes and data

Reference	Walter et al., 2012 [21]	Weber et al., 2013 [34]	Ebinger et al., 2014 [24]	Wendt et al., 2015 [35]	Ebinger et al., 2015 [32]	Wu et al., 2014 [36]	Bowry et al., 2015 [33]	Cerejo et al., 2015 [25]	Rasmussen, 2015 [37]	Itrat et al., 2016 [38]	Taqui et al., 2017 [39]	Mercy Health, 2017[a]	Data range
Site	Homburg, Saarland, Germany	Berlin, Germany	Berlin, Germany	Berlin, Germany	Berlin, Germany	Houston, TX, USA	Houston, TX, USA	Cleveland, OH, USA	Cleveland, OH, USA	Cleveland, OH, USA	Cleveland, OH, USA	Toledo, OH, USA	
Study design	RCT	pilot	RCT	RCT	post hoc analyses	pilot feasibility	RCT	retrospective analysis	report	prospective observational study	prospective analysis	prospective analysis	
Year(s)	2008–2011	2011	2011–2013	2011–2013	2011–2013	UNK	May 2014 to August 2014	2014	2014–2015	2014–2015	July 2014 to November 2014	January 2016 to July 2016	
Number of stroke patients with vs. without intervention	53 vs. 47	23 vs. 22	(1,804) 3,213 vs. 2,969	(1,804) 3,213 vs. 2,969	(1,804) 3,213 vs. 2,969	40	24 vs. 2	5	100 vs. 56	100 vs. 56	100 vs. 53	105 vs. 143	
Intervention	MSU	MSU-administered tPA	STEMO deployment	STEMO deployment	STEMO deployment	in-ambulance telemedicine rapid stroke evaluation	MSU-administered treatment	MSU deployment to intra-arterial therapy	MSU-administered tPA	MSU-administered treatment	MSU-administered treatment	MSU-administered treatment	
Age: mean ± SD/median (IQR)	UNK/72 (59–76)	74 ± 12/77 (66–82)	73.9 ± 15.0/ UNK	73.9 ± 15.0/ UNK	73.9 ± 15.0/ UNK	UNK	UNK/64	UNK/75 (51.5–81)	UNK/62 (53–76)	UNK/62 (53–76)	UNK/62 (53–78)	70.8±15.2/73 (63–82)	51.5–82 years old
Male sex, *n* (%)	31 (58.0)		795 (44.1)	646 (44.1)	795 (44.1)	UNK	13 (50.0)	3 (60)	46 (46)	46 (46)	46 (46)	49 (46.7)	44.1–58.0%
Hx of hyper-tension, *n* (%)	41 (77.0)		UNK	UNK	UNK	UNK	16 (61.5)	UNK	UNK	UNK	UNK	63 (60.0)	60.0–77.0%
Hx of DM, *n* (%)	14 (26.0)		451 (25.0)	451 (25.0)	451 (25.0)	UNK	4 (15.4)	UNK	UNK	UNK	UNK	27 (25.7)	15.4–26.0%
Hx of atrial flutter or fibrillation, *n* (%)	12 (23.0)		440 (24.4)	440 (24.4)	440 (24.4)	UNK	5 (19.2)	UNK	UNK	UNK	UNK	19 (18.1)	18.1–24.4%
Hx of stroke, *n* (%)	16 (30.0)		UNK	UNK	UNK	UNK	UNK	UNK	UNK	UNK	UNK	34 (32.4)	30.0–32.4%
NIHSS score, median (IQR)	5 (3–11)	7 (4–12)	10 (3–19)	UNK	10 (3–19)	8.5	11 (3–25)	19 (18.5–21.5)	6 (2–12)	6 (2–12)	6 (2–12)	UNK	2–19
mRS, median (IQR)	4 (2–5)	1 (0–3)	UNK	UNK	UNK	UNK	UNK	UNK	UNK	UNK	UNK	UNK	0–5
Dx of ischemic stroke	29 (55.0)		614 (70.9)	610 (33.8)	614 (70.9)	32	11 (42.3)	5 (100)	33 (33.0)	33 (33.0)	UNK	43 (41.0)	33.8–100%
Dx of TIA	8 (15.0)		182 (21.0)	185 (10.3)	182 (21.0)	8	1 (3.85)	UNK	4 (4.0)	4 (4.0)	UNK	13 (12.4)	4.0–15.0%
Dx of intracranial hemorrhage	4 (6.0)		45 (5.2)	45 (2.5)	45 (5.2)	UNK	4 (15.4)	UNK	5 (5)	5 (5)	UNK	5 (4.8)	2.5–15.4%
Thrombectomy	UNK		UNK	UNK	UNK	UNK	UNK	UNK	UNK	UNK	UNK	8 (7.6)	7.6%

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Table 2 (continued)

Reference	Walter et al., 2012 [21]	Weber et al., 2013 [34]	Ebinger et al., 2014 [24]	Wendt et al., 2015 [35]	Ebinger et al., 2015 [32]	Wu et al., 2014 [36]	Bowry et al., 2015 [33]	Cerejo et al., 2015 [25]	Rasmussen, 2015 [37]	Itrat et al., 2016 [38]	Taqui et al., 2017 [39]	Mercy Health, 2017[a]	Data range
Dx of seizure	7 (13.0)		UNK	129 (7.2)	UNK	UNK	4 (15.4)	UNK	UNK	UNK	UNK	13 (12.4)	7.2–13.0%
Dx of brain tumor	UNK		UNK	UNK	UNK	UNK	UNK	UNK	UNK	UNK	UNK	1 (0.95)	0.95%
Dx of head trauma	UNK		UNK	9 (0.5)	UNK	UNK	UNK	UNK	UNK	UNK	UNK	1 (0.95)	0.5–0.95%
Treated with IV tPA, *n* (%)	12 (23)		192 (10.6)	UNK	200 (11.1)	UNK	12 (46.2)	5 (100)	16 (16.0)	16 (16.0)	16 (16.0)	10 (9.5)	9.5–100%
Alarm to therapy decision, min	35 (31–39)		UNK	UNK	UNK	9.77	UNK	UNK	UNK	UNK	UNK	UNK	9.77–39
Alarm to treatment, mean (95% CI)/ median (IQR), min	UNK/38 (34–42)	62 (21)[b]/ 58 (50–65)	51.8 (49.0–54.6)/ 48 (39–56)[c]	UNK	51.8 (49.0–54.6)/ 48 (39–56)[c]	9.27	UNK	93 (75–116.5)	51.8	UNK	UNK	50.6 (44.4–56.8)/ 53.0 (42–59)	34–116.5
LKW to treatment, mean (range)/ median (IQR), min	UNK/72 (53–108)		UNK	UNK	UNK	UNK	98 (47–265)/ UNK	UNK	UNK	UNK	UNK	95.4 (40–153)/ 105 (52.0–128.8)	40–265
MSU on-scene to tPA time, mean (range), min	UNK	48 (22)/ 42 (37–52)[d]	UNK	UNK	UNK	UNK	25 (18–42)	UNK	UNK	UNK	UNK	34.7 (25–49)	18–52
Alarm to imaging, mean (95% CI)/ median (IQR), min	UNK/alarm to end of imaging 34 (30–38)		37.7 (35.6–39.7)/ 35 (30–42)	UNK	37.7 (35.6–39.7)/ 35 (30–42)	UNK	UNK	UNK	37.7	UNK/alarm to end of imaging 33 (22–46)	36 (34–38)/ 33 (29–41)	29.5 (28.0–31.0)/ 30.0 (24.3–33.3)	22–42
Alarm to INR, mean (95% CI)/ median (IQR), min	UNK		30.8 (28.4–33.2)/ 26 (20–37)	UNK	30.8 (28.4–33.2)/ 26 (20–37)	UNK	UNK	UNK	UNK	UNK	34 (32–36)/ 34 (25–40)	28.5 (21.6–35.4)/ 28.5 (26.8–32.0)	20–40
LKW to tPA <60 min, *n* (%)	UNK		UNK	UNK	62	UNK	12 (33.0)	UNK	31%	UNK	UNK	3 (30.0)	30.0–33.3%

CI, confidence interval; DM, diabetes mellitus; Dx, diagnosis; Hx, history; INR, international normalized ratio; IV, intravenous; IQR, interquartile range; LKW, last known well; mRS, modified Rankin Scale; MSU, mobile stroke unit; NIHSS, National Institutes of Health Stroke Scale; RCT, randomized clinical trial; SD, standard deviation; STEMO, stroke emergency mobile; TIA, transient ischemic attack; tPA, tissue plasminogen activator; UNK, unknown. [a] First published data from the Mercy Health MSU's first 6 months of operation. [b] Mean (SD). [c] One patient missing. [d] Mean (SD), median (IQR).

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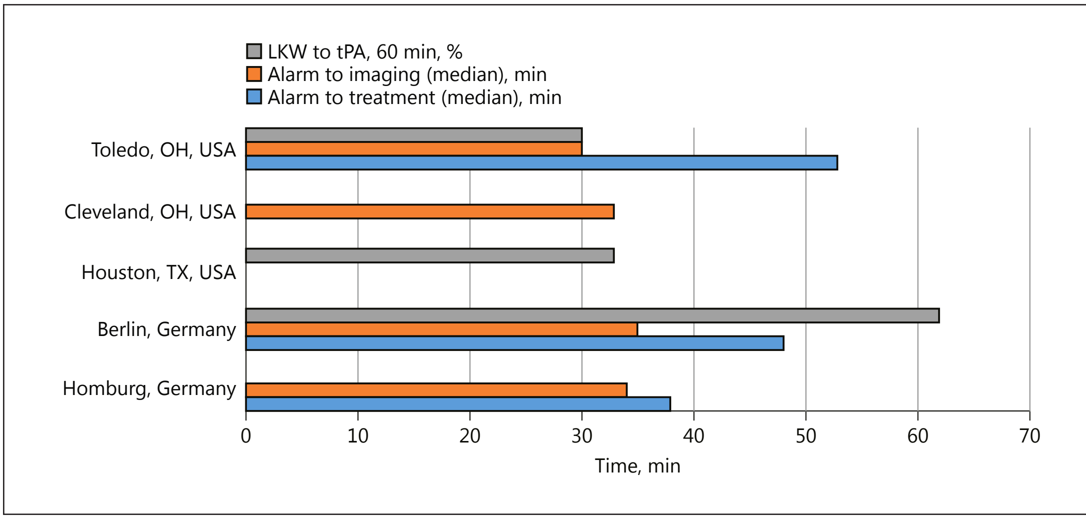

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Fig. 3. Mobile stroke unit time metrics comparison. LKW, last known well; tPA, tissue plasminogen activator.

bolysis with MSU implementation demonstrated in Germany has also been shown to be reproducible in prehospital settings outside of Germany as well [33]. Published MSU clinical outcomes and data can be found in Table 2 and a time metrics comparison in Figure 3.

Discussion

Feasibility of Implementation

The funding and building of a MSU from first concept to implementation within 11 months in Houston attests to the feasibility of implementing MSUs around the world. Creative efforts taken to keep MSU costs down at startup, such as the implementation of ambulance designs already used by local EMS and collaboration with local stakeholders, can make project startup more feasible and affordable for all parties [10]. Further, the MSU team could also become smaller, and possibly more economically viable, through reducing personnel cost by cross-training team members. In the future, a team could include three individuals on board: a paramedic, an emergency medical technician, and a critical care nurse; they could carry out patient care, conduct the CT scan, and interact with a remote VN via telemedicine [10]. Other areas of the United States healthcare system may require more attention to ease MSU implementation, including addressing the high cost of tPA [22]. There currently exists no Centers for Medicare & Medicaid Services billing code to reimburse the Houston MSU for the cost of recombinant tPA given in the prehospital environment.

Future Research

The benefits of a MSU extend beyond the treatment of ischemic strokes with tPA to include hemorrhagic strokes and other acute neurological emergencies. As MSUs become more widespread, more research is necessary to provide further cost-benefit analysis. Additionally, further studies are needed to assess whether improved treatment times result in more favorable patient outcomes [32]. Future research may also determine definitively whether a MSU can optimize the identification and diagnosis of large vessel occlusions with higher sensitivity and specificity, as well as post-tPA interventional management.

Summary and Conclusions

Initially hypothesized in 2003, the first MSUs came to fruition in Germany and were adopted worldwide in acute, prehospital stroke management. These specialized ambulances have made the diagnosis and treatment of many neurological emergencies, in addition to ischemic and hemorrhagic stroke, possible directly at the emergency site. As MSUs continue to collect data and improve their methods, shortened time metrics are expected, as well as an increase in the number of acute neurological patients who can benefit from rapid treatment and improved outcomes in the prehospital setting.

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Disclosure Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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