REVIEW

Prehospital stroke management and mobile stroke units

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Purpose of review

Delayed presentation at the hospital contributes to poorer patient outcomes and undertreatment of acute stroke patients. This review will discuss recent developments in prehospital stroke management and mobile stroke units aimed to improve timely access to treatment within the past 2 years and will point towards future directions.

Recent findings

Recent progress in research into prehospital stroke management and mobile stroke units ranges from interventions aimed at improving patients help-seeking behaviour, to the education of emergency medical services team members, to the use of innovative referral methods, such as diagnostic scales, and finally to evidence of improved outcomes by the use of mobile stroke units.

Summary

Understanding is increasing about the need for optimizing stroke management over the entire stroke rescue chain with the goal of improving access to highly effective time-sensitive treatment. In the future, we can expect that novel digital technologies and artificial intelligence will become relevant in effective interaction between prehospital and in-hospital stroke-treating teams, with beneficial effects on patients outcomes.

Keywords

acute stroke, emergency medical services, prehospital, thrombectomy, triage

INTRODUCTION

Despite knowledge about the time-sensitivity of recanalizing treatments and decades of efforts aimed at streamlining systems of care, only a minority of stroke patients actually receive timely treatment. For optimization of processes, acute stroke management should be viewed as a continuous stroke-rescue chain, starting with symptom onset and ending with recanalization, but complicated by multiple crucial interfaces as causes of errors and delays (Fig. 1) [1■■].

This manuscript will summarize recent developments and is based on a PubMed database search for articles containing the term stroke in combination with prehospital or mobile stroke unit (MSU) and published between 1 January 2021, and 31 December 2022.

CRUCIAL PREHOSPITAL DELAYS

The problem of delays before treatment is corroborated by the evaluation of a nationwide registry in Denmark that included 5356 stroke episodes. The study found that only 2405 (43%) of the patients arrived at the stroke centre within 3 h and that delays detrimentally affected treatment rates [2]. A study of 11 Korean Regional Centers involving 17 895 stroke patients found that not using emergency medical services (EMS) is a key determinant of hospital arrival more than 3 h after the event [3]. Explaining the observed current delays data collected from 2014 to 2019 by the Paul Coverdell National Acute Stroke Program involving 500 829 patients with stroke or transient ischemic attack (TIA) showed that only 60% of the patients arrived via EMS [4].

As a possible solution to the problem of prehospital delays and poor help-seeking behaviour, public education campaigns have been set up. A most

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KEY POINTS

- Optimizing stroke management must consider streamlining processes over the entire stroke rescue chain, ranging from symptom onset to recanalization.
- Recent progress in research on prehospital stroke management includes studies on patients help-seeking behaviour, innovative referral strategies and deployment of MSUs.
- In the future, innovations in technology and artificial intelligence will facilitate communication between pre- and in-hospital stroke treating teams and improve efficiency of use of MSU, with beneficial effects on patients outcomes.
- Future research may clarify the role of prehospital delivery of treatments, such as new neuroprotectants and treatments to prevent haematoma enlargement.

recent before-after study from China found that a persistent, multifaceted campaign increased the rate of arrival at the hospital within 3 h of the event from 5.8 to 33.4% ($P < 0.001$) [5].

Also, the need for improvement in the identification of stroke by EMS personnel in the EMS communication centre or in the field was addressed in an analysis of data from the Australian Stroke Clinical Registry. Stroke or TIA was identified by only 56% of call-takers and 69% of paramedics. Patients with correctly identified events arrived at hospitals earlier [6].

REFERRAL MODELS FOR ACUTE STROKE DRIP AND SHIP VS. MOTHERSHIP

A rapidly growing field in acute stroke research is the development of referral strategies for acute stroke patients. Each proposed strategy has its strengths and weaknesses. Traditionally, the focus of stroke management was on the fastest possible provision of thrombolytic treatment, and primary stroke centres (PSCs) were the first choice of target hospital. Also, in the current thrombectomy era, current guidelines recommend transferring stroke patients to the nearest stroke centre. This is called the 'drip and ship' approach, if thrombolysis is administered before secondary transfer from a PSC to a comprehensive stroke centre (CSC), for intraarterial treatment (IAT) as opposed to the 'mothership' strategy, which refers to direct admission to a CSC. The advantage of the 'drip and ship' concept is that most patients (65–90%) without large-vessel occlusion (LVO) may receive thrombolysis earlier at a nearby PSC.

However, studies have shown that for patients with LVO, secondary transfers from a PSC to a CSC for specialized stroke treatment are associated with detrimental delays and, thus, with a pronounced increase in infarct size as an indicator of harm [7]. In search of the optimal referral strategy, a modelling study of 242 874 emergency admissions in England showed that most of the inhabitants of England would gain the greatest clinical benefit from direct conveyance to a stroke centre capable of administering IAT, although the study also discussed the real-life feasibility of such an approach given the potential destabilization of the EMS system [8].

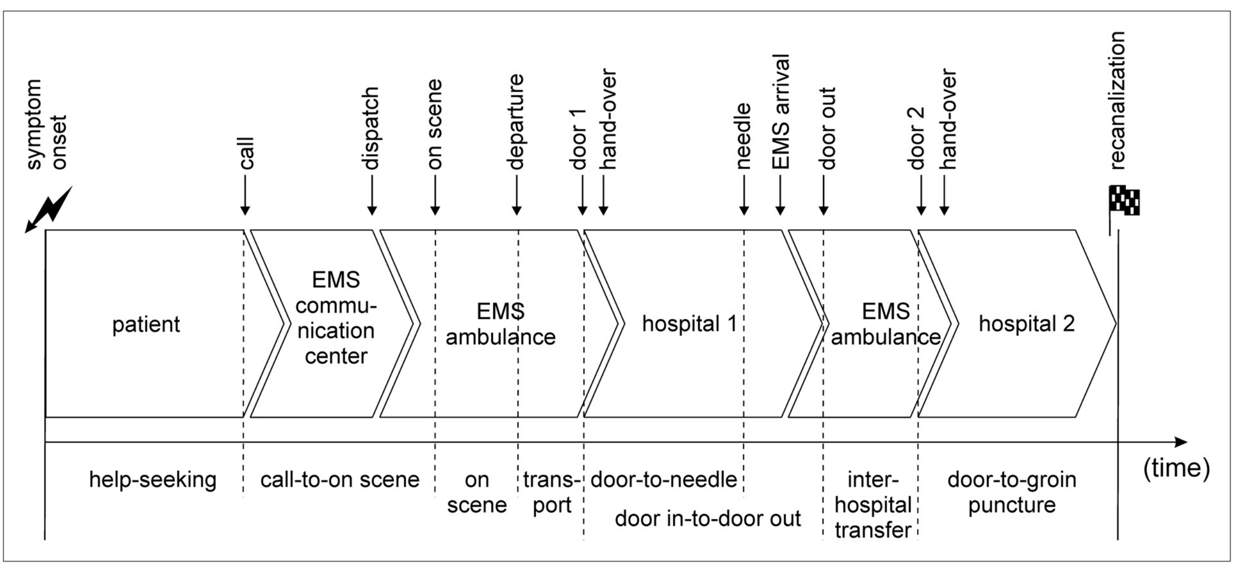

FIGURE 1. Stroke rescue chain ranging from symptom onset to recanalization. The diagram shows milestones, players and crucial intervals and intersections of acute stroke management. Adapted from [1■■].

Another modelling study focusing on healthcare economics concluded that the 'drip and ship' approach may have a slight advantage over the 'mothership' approach in regard to expected costs [9]. In general, the answer to 'drip and ship' remains unclear and more research is required to understand the preferred approach for a specific region.

Mobile interventionist teams

Earlier studies demonstrated the feasibility and time gains associated with the concept of the mobile interventionist team approach. This approach involves sending an interventionist team from a CSC to a PSC to perform thrombolysis there, so far by ambulances or other vehicles. A recent non-randomized controlled interventional study using helicopters found that times to treatment were shorter for 60 LVO patients in the intervention group than for 57 LVO patients in the control group [58 (51–71) vs. 148 (124–177) min; $P < 0.001$]. However, the difference between the groups in modified Rankin Scale (mRS) scores after 3 months was not statistically significant [10■■].

Obviously, this approach places high demands on the PSC in terms of hospital workflow and available resources and makes the PSC very similar to a CSC.

Use of prehospital scales as a strategy for triage of stroke

The use of clinical scales aimed at detecting patients who are highly likely to have stroke due to LVO for triage decision-making can be viewed as a distinct referral strategy. Although a few sites already use LVO scales for triage decision-making, these scales are often still considered to be experimental and are not recommended by stroke guidelines.

The Los Angeles Motor Scale (LAMS), which focuses only on motor symptoms, does not require too much training and can be completed within 1 min. Thus, the LAMS is suitable for use in prehospital emergency care protocols, as has recently been shown. In 2015, the LAMS was implemented statewide in Saarland, Germany, for use in triage decision-making [11]. A subsequent prospective analysis of data from 1123 consecutive patients treated during a 4-month period in a statewide network of all stroke-treating hospitals showed that using the LAMS allowed triage decisions according to LVO status with a sensitivity of 69.2% and a specificity of 84.9%. Secondary transfers were required for only 17.9% of the LVO patients [12■■].

The large multicentre, cluster-randomized Transfer to the Closest Local Stroke Center vs. Direct Transfer to Endovascular Stroke Center of Acute Stroke Patients With Suspected Large Vessel Occlusion in the Catalan Territory (RACECAT) trial was performed in Catalonia, Spain. It involved 1401 patients with suspected LVO (diagnosis was based on use of the Rapid Arterial Occlusion Evaluation (RACE) score) who were directly transferred either to a thrombectomy-capable centre or to the closest local centre. Although stroke management metrics and treatment rates were significantly improved in the intervention group, the study found neither significant differences in 90-day neurological outcomes nor in mortality rates [13■■].

A recent study performed in the U.S. state of South Carolina found that a RACE scale score of 5 or higher had a sensitivity of 0.71, a specificity of 0.65 and an accuracy of 0.66 in detecting patients with stroke caused by LVO [14].

A county-based study using the Cincinnati Prehospital Stroke Scale (CPSS) for triaging in Atlanta, Georgia, found that the likelihood of diagnosing LVO was higher when this scale was used than when it was not [odds ratio (OR), 8.5; 95% confidence interval (CI), 5.0–14.4; $P < 0.001$] [15].

Moreover, the modified Gaze-Face-Arm-Speech-Time scale has been tested with 150 consecutive patients; findings indicate improvements in dispatch-to-groin puncture time [16]. Finally, the Japan Urgent Stroke Triage scale was studied at 13 centres in Hiroshima, Japan, as a tool for detecting LVO patients for direct transfer. The 2406 patients treated after implementation of this scale had shorter door-to-puncture times than did the 2735 patients treated before its implementation (73 vs. 84 min; $P = 0.03$). However, outcomes were not improved [17■■].

The main limitation of all LVO scales is that they miss a sizable number of LVOs. Thus, a recent evaluation of various LVO scales involving 2415 patients showed that all studied scales had sensitivities ranging from 63 to 78% and specificities ranging from 72 to 73%, with no statistically significant differences between scales [18]. Similarly, another recent study involving 1033 patients with suspected stroke underlined that the probability of LVO remains high despite negative findings by LVO tests [19]. As one explanation of this finding, a recent study involving 1588 participants showed that prehospital fluctuations of stroke symptoms are quite common, occurring in 35.5% of patients [20].

Possibly, the combination of the use of clinical scales and teleconsultation between the prehospital and in-hospital teams can improve diagnostic accuracy. This is suggested by a study performed in Stockholm, Sweden, in which patients were scored with a clinical scale followed by ambulance-to-hospital teleconsultation for triage decision-making. LVO patients in the intervention group ($n = 240$) had better management metrics and better outcomes than did LVO patients in the pre-intervention group (34.6 vs. 23.7%; $P = 0.014$) [21]. Similarly, use of an LVO scale has been studied in a telemedicine-equipped MSU, with positive effects [22].

Mobile stroke units as triage tools

A further distinct referral strategy is the use of a MSU-based vascular imaging for triage decision-making. Multimodal imaging in the MSU, including computed tomography (CT) angiography [23–25], allows not only the differential treatment of ischemic and haemorrhagic strokes in the field [23,26] but also triage decision-making with 100% sensitivity and 100% specificity [11].

For the future, we can anticipate that, rather than one single referral model, various solutions for referral of stroke patients will be applied according to local geographic barriers, availability of healthcare resources, jurisdictions and reimbursement policies.

MOBILE STROKE UNITS

In contrast to the current practice of transporting the patient to the nearest hospital for diagnosis and treatment there, a scientific concept for the delivery of stroke treatment directly at the emergency site was first published in 2003 [27] and first introduced in clinical practice in 2008 [26]. This concept was based on the use of imaging, a point-of-care (POC) laboratory, telecommunication and advanced medication in an ambulance [28▪▪].

Clinical evidence

The first randomized trial on MSUs involving 100 patients, performed in Homburg/Saar, Germany, between 2008 and 2011, showed dramatically reduced alarm-to-therapy decision times of 35 min (range, 31–39 min) for the MSU group as compared with 76 min (range, 63–94 min; $P < 0.001$) for the standard-of-care control group [23]. Although many additional studies have confirmed the effect of MSUs on stroke management metrics and thrombolysis rates, only recently have the effects of MSUs on long-term patient outcomes been demonstrated.

The recent large controlled trial [Berlin PRehospital Or Usual Delivery of Acute Stroke Care (B_PROUD)] performed in Berlin, Germany, found that 749 patients in the MSU group (MSU available) exhibited significantly better outcomes at day 90 than did 794 patients in a conventional treatment group (MSU not available). Specifically, 51% of patients in the MSU group and 42% of those in the control group exhibited good outcomes (mRS score, 0–1; OR, 1.49; 95% CI, 1.19–1.89) [29▪▪]. More recently, a further evaluation of this B_PROUD study extended by data from a registry confirmed that the use of MSUs improved 3-month functional outcomes, regardless of subtype of stroke or potential reperfusion therapies [30].

Coordinated in Houston, Texas, another large controlled, multicentre trial [BEnefits of Stroke Treatment Delivered Using a Mobile Stroke Unit Compared to Standard Management by Emergency Medical Services (BEST-MSU)] involved patients eligible for tissue plasminogen activator (tPA). The outcome of 617 patients treated in MSUs was better than that of 430 patients given conventional treatment: 55.0% of patients in the MSU group and 44.4% of those in the control group achieved an mRS score of 0 or 1 at day 90 (OR, 2.43; 95% CI, 1.75–3.36) [31▪▪].

Finally, a meta-analysis of controlled studies involving 3228 patients in various study settings confirmed that the use of the MSU strategy is beneficial. Compared with standard care, MSU use was associated with excellent outcome (mRS score of 0 to 1 at 90 days; OR, 1.64; 95% CI, 1.27–2.13; $P < 0.001$). Stroke management metrics were also superior with the MSU, whereas indicators of safety were not affected [32].

Such evidence was the rationale for the 2022 guidelines of the European Stroke Organization, which suggest the 'use of MSUs over conventional care for the prehospital management of patients with suspected stroke' because 'in patients with acute ischemic stroke, prehospital management with an MSU improves functional outcomes, increases the rates of intravenous thrombolysis, including the rates of thrombolysis within the golden hour, and shortens onset to treatment time without any safety concerns' [33▪▪].

FUTURE DIRECTIONS AND CONCLUSION

Telemedicine, smartphone applications and artificial intelligence for acute stroke management

In the future, we can expect that digital solutions with telemedicine, smartphone applications and artificial intelligence will play an increasing role in acute stroke management. In this regard, a recent community-based, cluster-randomized study confirmed that prehospital telestroke assessment is accurate and superior to other options in predicting reperfusion candidates [34]. Moreover, a digital communication smartphone application was evaluated for a study period of 12 months. The results showed that its use improved door-to-CT times for 215 intervention patients as compared with 389 controls [27 min (18–44) vs. 71 min (43–147); $P=0.0001$] [35]. Similarly, a further study found that an application-based stroke scale used on smartphones in the field achieved good accuracy in detecting LVO [36].

A recent study involved patients transported by the Chicago EMS to 17 regional PSCs and CSCs, found that stroke identification rates could be improved by machine learning using earlier EMS protocols as input [37]. Although previous studies have shown that such technologies based on smartphone applications are acceptable and feasible and that they may achieve time gains, their effect on outcomes still remains to be explored.

Novel diagnostic and therapeutic options in ambulances and mobile stroke units

In the future, we may see the use of novel technologies for detecting stroke and LVO in ambulances or MSUs, such as ultrasound techniques [38], electroencephalography [39], near-infrared spectroscopy, microwave technology and volumetric impedance spectroscopy [40].

Regarding treatments, tenecteplase may in the future be well suited for use in MSUs because it can be administered as a single bolus. A randomized phase II trial involving patients with ischemic stroke who were assessed in an MSU found statistically significant improvements in early reperfusion, as measured by the post-lysis volume of the CT perfusion lesion after hospitalization (median, 12 vs. 35 ml; $P=0.003$) [41].

Apart from recanalizing treatment, clarification of the cause of stroke symptoms may enable differential adjustment of blood pressure in stroke subtypes even at the emergency site [23,26]. In this regard, a study involving 426 patients with intracranial haemorrhage found that elevated prehospital blood pressure increased haematoma expansion and in-hospital mortality rates [42]. An MSU-based study showed that haematoma enlargement occurred in 28% of patients during the prehospital phase of disease [43]. In the future, more studies of prehospital treatments can be expected, as exemplified by a recent prehospital study of the use of the neuroprotectant, glyceryl trinitrate [44].

Regarding MSUs, there is still much room for future research. The rational and cost-efficient integration of MSUs into real-life EMS practices may be improved by their use for additional emergencies

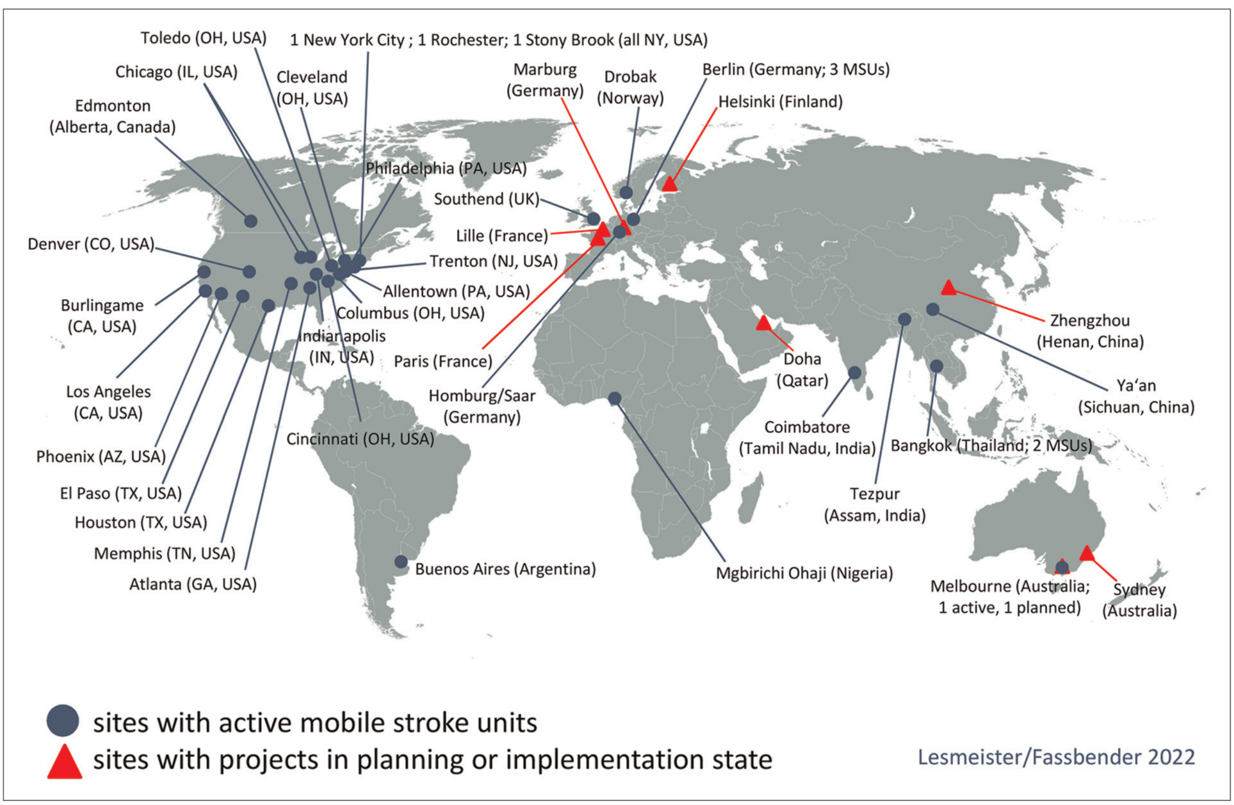

FIGURE 2. World map of Mobile Stroke Unit projects [28■■].

beyond stroke. Specifically for this reason, a 'Hybrid-MSU', an MSU with extended capabilities (radiography, ultrasonography, refined POC laboratory, electrocardiography, electroencephalography and advanced medications and so on), has been tested. Results suggest that mainly cerebral conditions other than stroke, such as traumatic brain injury, subarachnoid haemorrhage and status epilepticus, may also profit from diagnosis, accurate triage decision-making and treatment directly at the emergency site [45].

Regarding staffing of MSUs, one study found that not only vascular physicians but also anaesthesiologists can diagnose and treat stroke in MSUs [46]. Finally, a study in Houston, Texas, and Los Angeles, California, investigated the use of artificial intelligence to evaluate CTA images, with promising accuracy [47].

Since hitting the road in 2008 in Homburg, Germany, the MSU concept is now spreading across the world (Fig. 2), and it can be expected that many still open research questions such as cost-efficiency and best setting can be resolved by the many further projects sites.

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Conflicts of interest

There are no conflicts of interest.

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- ▪ of special interest
- ▪▪ of outstanding interest

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