Stroke: Vascular and Interventional Neurology

ORIGINAL RESEARCH

Hybrid-Mobile Stroke Unit: Opening the Indication Spectrum for Stroke Mimics and Beyond

Klaus Fassbender, MD; Daniel J. Phillips; Iris Q. Grunwald, MD; Andrea Schottek; Sajid Alam, MD; Saman Perera, MD; Annie Chakrabarti, MD; Robert Moon; Martin Lesmeister; Viola Wagner, MD; Damon Wheddon; David Dommett; Brittany Wells; Rheanne Middleton; Robert Willis; Monika Bachhuber; Fatma Merzou, MD; Stefan Wagenpfeil, PhD; Jineesh Thottath, MD; Thomas Bertsch, MD; Silke Walter, MD; for the Hybrid-MSU Working Group

BACKGROUND: Despite proven benefits, the use of single-purpose mobile stroke units (MSUs) has raised concerns about their effective and cost-efficient integration into clinical practice, especially when considered for operation in nonurban areas. The MSU concept may benefit from opening the indication spectrum to include frequent stroke mimics and additional emergencies.

METHODS: The current observational study evaluated benefits for the treatment and triage decision-making of use of an MSU with extended capabilities (Hybrid-MSU), also including radiography, ultrasonography, extended point-of-care laboratory, ECG, electroencephalography, and advanced medications. Apart from patients with a dispatch code for "stroke", the ambulance was also dispatched to those with codes for "seizures", "falls with head trauma", "headache", "unconsciousness", "infection and pandemic", "chest pain", and "breathing problems".

RESULTS: For 250 patients treated by the Hybrid-MSU, but not for 250 conventionally treated patients, the prehospital diagnostic workup allowed, apart from treatment with stroke thrombolytics (n=15), prehospital administration of specific anticonvulsants (n=15), antibiotics (n=5), early secondary stroke prophylaxis with aspirin (n=49), and the Sepsis Six bundle (n=2). Prehospital diagnosis avoided 215 (86.0%) admissions to the emergency department, either by management at home (n=116, 46.4%) or by directly transferring patients to the required specialized wards (n=99, 39.6%).

CONCLUSION: The current study demonstrates the feasibility of the use of a Hybrid-MSU and indicates its potential benefits for prehospital treatment and triage decision-making. Opening the indication spectrum, together with an act-alone ability, could be a key in the future integration of MSUs into routine health care.

Key Words: mobile stroke unit ■ prehospital ■ stroke

Chances of success for emergency treatment are optimal during the "golden hour" and rapidly decline thereafter. Therefore, the fastest possible delivery of treatment is recommended for key emergencies such as seizures/status epilepticus,[1,2] stroke,[3] traumatic brain injury,[4] sepsis,[5] and acute coronary syndromes.[6] However, treatment is often delayed by awaiting hospital arrival for diagnostic clarification.

Moreover, because of insufficient diagnostic clarification in the prehospital setting, it is often difficult to

Correspondence to: Klaus Fassbender, MD, Department of Neurology, Saarland University Medical Center, 66421 Homburg, Germany. E-mail: klaus.fassbender@uks.eu

Supplementary Material for this article is available at https://www.ahajournals.org/doi/suppl/10.1161/SVIN.122.000482

Stroke: Vascular and Interventional Neurology is available at: www.ahajournals.org/journal/svin

determine whether a patient requires hospital admission. For undiagnosed patients, the standard approach is transport to the nearest emergency department (ED), although many of these patients could be safely managed at home.[7]

Specifically, for the treatment of stroke directly at the emergency site, mobile stroke units (MSUs) incorporating computed tomography, point-of-care laboratory, and telemedicine have been developed and implemented.[8,9] Their benefits in reducing time-to-treatment[10,11] and improving clinical outcomes[12,13] have previously been demonstrated. Benefits also include diagnosis-based triage decision-making, ie, direct transfer of patients with large-vessel occlusion, as identified in the ambulance by computed tomography angiography, to comprehensive stroke units for thrombectomy rather than to the nearest stroke center without endovascular capabilities.[11]

Concerns exist, however, regarding the rational and cost-efficient integration of single-purpose MSUs into regular health care, especially in suburban and rural areas with fewer stroke calls and larger catchment areas. Importantly, the dispatch code "stroke" frequently turns out to be other emergencies (stroke mimics), many of them requiring additional regular emergency medical services (EMS) support. Therefore, a wide-spectrum MSU with act-alone ability could improve management of these patients without requiring additional EMS resources. Here, we evaluate the feasibility and potential benefits of prehospital treatment and triage decision-making of a multipurpose MSU (Hybrid-MSU), which incorporates advanced equipment for the treatment of a larger spectrum of emergencies.

Nonstandard Abbreviations and Acronyms

MSU	mobile stroke unit

CLINICAL PERSPECTIVE

- Implementation of mobile stroke units (MSUs) with extended capabilities (radiography, ultrasonography, advanced laboratory testing, ECG, and electroencephalography) (Hybrid-MSU) into the routine emergency medical service is feasible.
- A Hybrid-MSU may allow earlier treatment and better triage decision-making of emergencies also beyond stroke such as seizures/status, falls and head trauma, and infections.
- Depending on the setting, opening of the indication spectrum of the MSU and an "act-alone" capability may improve integration of MSUs into routine health care.

METHODS

Patients and Inclusion Criteria

In this observational cohort study, between May 2020 and February 2021 the EMS dispatch center dispatched the Hybrid-MSU to 250 patients (aged ≥18 years) with the following codes: "stroke", "seizures", "falls with head trauma", "headache", "unconsciousness", "infection and pandemic", "breathing problems", and "chest pain". A total of 250 conventionally treated patients with the same dispatch codes and during the same period served as the control group for the comparison of management metrics. Finally, for comparison we analyzed anonymous data from all patients treated by the EMS in the same catchment area, same time, and same code spectrum in regard to rates of hospital admission.

The Hybrid-MSU was stationed at the East of England Ambulance Service National Health Service Trust EMS station in Martlesham, Suffolk, UK, and operated within a 20-mile radius in East Suffolk on Monday through Friday from 9 AM to 5 PM. East Suffolk has a population density of 198.5/km^2.

The Hybrid-MSU ambulance was dispatched as an independent emergency ambulance according to conventional emergency ambulance dispatch pathways.

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Technologies and Staffing

The Hybrid-MSU is an ambulance containing a wide spectrum of diagnostic devices, including: (1) an accumulator-driven computed tomography scanner (Ceretom, Neurologica/Samsung) enabling cranial multimodal imaging of the head; (2) a radiography system (Leonardo Dr nano, Oehm and Rehbein) for chest imaging; (3) an ultrasound device (GE Vscan Extend Dual Probe Ultrasound Machine, National Ultrasound) allowing focused assessment with sonography in trauma emergency investigation; (4) an ECG device (Corpuls); (5) an electroencephalography (EEG) device (8-lead EEG, Enobio EEG System, Neuroelectrics); and (6) a highly complex point-of-care laboratory system,

including the following devices: PocH 100i (Sysmex) for differential blood cell count; CoaguChek Pro system (Roche Diagnostics) for determining international normalized ratio; Cobas h 232 POC system (Roche, for Troponin T, D-dimer, and N-terminal pro-B-type natriuretic peptide; iStat system (Abbott) for urea, creatine kinase, electrolytes, and blood gases; Quick-read go (Aidian) for C-reactive protein measurement; Willi Fox Procalcitonin Test cartridge (Willi Fox) for qualitative procalcitonin measurement; and qualitative toxicology Drug-Screen Multi 8XA blood test (nal von minden).

Therapeutically, advanced medication on-board included:

(1) specific anticonvulsive agents (levetiracetam); (2) antibiotics; (3) thrombolytic agents; (4) vitamin K; (5) intensified circulation and blood pressure management medications (labetalol, intravenous glyceryl trinitrate, metaraminol); (6) Sepsis Six bundle equipment (blood cultures, high-flow oxygen, IV antibiotic treatment, fluid treatment, urine output documentation, serum lactate); and (7) advanced Areogen inhalation management equipment (vibrating mesh aerosol drug delivery system Aerogen Solo Aerogen), which delivers the inhaled drug deep into the alveoli, eg, for patients with exacerbations of chronic obstructive pulmonary disease or asthma.

The Hybrid-MSU was operated by a 2-person team consisting of a physician and a paramedic. In accordance with local regulations, the physician performed the radiological examinations. Additional medical/radiological guidance was available via telecommunication.[9,10] Its multifunctionality allowed the Hybrid-MSU to act without adjunct regular EMS.

Study Variables

We studied the feasibility of prehospital delivery of treatments for a widened spectrum of emergencies beyond thrombolysis, including administration of specific anticonvulsants, antibiotics, vitamin K, circulation management, Sepsis Six bundle, and advanced inhalation treatment in the Hybrid-MSU as compared with the control group.

Concomitantly, we investigated the avoidance of admission to the ED, either by ambulatory treatment, referral to primary care, or transfer to specialized wards. We compared emergency metrics and mortality rates as safety measures of the Hybrid-MSU–treated group with 250 patients treated with standard ambulance. In addition, we evaluated hospitalization rates using anonymized data of all patients (n=3916) treated in the same catchment area, at the same time and with the same code spectrum.

Ethics and Statistical Analysis

The current study was approved for analysis of 500 participants by the Health Research Authority UK (IRAS 301852). Patients or their representatives provided written informed consent for participation. Categorical variables were described by frequency and percentage, and continuous variables were described by median and interquartile range (IQR). Mann–Whitney *U* test was used to compare metrics.

RESULTS

Prehospital Diagnosis and Treatment

In the missions for all of the 250 consecutive patients (median age, 74 years; IQR, 63–83 years; 133 women [53.2%]), the Hybrid-MSU acted alone, without being routinely supported by conventional ambulances on scene.

Interestingly, the rate of patients receiving a non-stroke diagnosis among the patients dispatched with code stroke was 51%. The rate of patients diagnosed with stroke, who were not dispatched with code stroke was 20% (Table 1). Hybrid-MSU patients were examined with noncontrast computed tomography (n=197) in case of new or undiagnosed acute cerebral symptoms, electroencephalography (n=8) in case of altered consciousness and suspected nonconvulsive seizures, ultrasound (n=4) to diagnose urinary retention/pleural effusion, and chest radiography (n=6) in case of suspicion of pneumonia, apart from ECG (n>75).

On the basis of the prehospital diagnostic results, Hybrid-MSU patients but not control patients (median age, 74 years; IQR, 60–85 years; 139 women [55.6%]) were treated with intravenous thrombolysis for stroke (n=15), aspirin for early secondary prevention of stroke (n=49), intravenous levetiracetam (n=15), antibiotics (n=5), and Sepsis Six bundle (n=2) (Table 1). Two patients with acute large-vessel occlusion ischemic stroke (1 patient with middle cerebral artery and 1 patient with basilar artery occlusion) were identified at the emergency site and were directly transported to the next thrombectomy-capable center. Examples of prehospital diagnosis-based emergency treatment and triage decision-making are presented in the Figure 1 and the equipment of the Hybrid-MSU and the potential use in the field are detailed in Table 2.

In contrast, despite their onboard availability, anticoagulant antagonization, intensified circulation interventions, and advanced inhalation or acute asthma treatment were not used. No other than conventional ambulance treatment for patients with coronary artery syndrome could be applied.

Table 1. Treatment and Triage in Patients Managed by a Hybrid-MSU

Final diagnoses, n (%)	Dispatch codes, n (%)	Prehospital diagnostic workup, n (%)	Specific prehospital treatments,* n (%)	Triage to A&E, n (%)	Triage to other than A&E, n (%)
Ischemic stroke 51 (20.4)	Stroke, 43 (84.3) Unconsciousness, 2 (3.9) Chest pain, 2 (3.9) Falls, 2 (3.9) Seizure, 1 (1.9) Headache, 1 (1.9)	CCT, 49 (96.1) 12-Lead ECG, 11 (21.6) Ultrasound, 1 (1.9) Electroencephalography, 2 (3.9)	IVT, 15 (29.4) Aspirin, 18 (35.3) Anticonvulsants, 2 (3.9)	3 (5.9)	Total, 48 (94.1) Stroke unit, 39 (76.5) Tertiary center cath lab, 2 (3.9) Left at home†, 7 (13.7)
TIA 40 (16.0)	Stroke, 34 (85.0) Falls, 2 (5.0) Unconsciousness, 2 (5.0) Diabetic problems, 1 (2.5) Pandemic, 1 (2.5)	CCT, 40 (100) 12-Lead ECG, 9 (22.5) Ultrasound, 2 (5.0) Chest X-ray, 1 (2.5)	Aspirin, 31 (77.5)	0	Total, 40 (100) Stroke unit, 7 (17.5) Left at home, 33 (82.5)
Infection/sepsis 19 (7.6)	Stroke, 12 (63.2) Chest pain, 2 (10.5) Headache, 2 (10.5) Breathing problems, 1 (5.3) Unconscious, 1 (5.3) Pandemic, 1 (5.3)	CCT, 11 (57.9) 12-Lead ECG, 7 (36.8) Chest X-ray, 3 (15.8)	Antibiotics, 3 (15.8) Fluids, 1 (5.3) Sepsis Six bundle, 1 (5.3)	6 (31.6)	Total, 13 (68.4) Stroke unit, 1 (5.3) AMU, 6 (31.6) Left at home, 6 (31.6)
Seizure 16 (6.4)	Stroke, 7 (43.8) Seizure, 7 (43.8) Breathing problems, 2 (12.5)	CCT, 12 (75.0) 12-Lead ECG, 4 (25.0) Electroencephalography, 4 (25.0)	Anticonvulsants, 9 (56.3)	0	Total, 16 (100) AMU, 7 (43.8) Left at home, 9 (56.3)
Falls and syncope/orthostatic hypotension 27 (10.8)	Falls, 12 (44.4) Stroke, 7 (25.9) Unconsciousness, 5 (18.5) Headache, 2 (7.4) Seizure, 1 (3.7)	CCT, 18 (66.7) 12-Lead ECG, 11 (40.7)		5 (18.5)	Total, 22 (81.5) AMU, 3 (11.1) Left at home, 19 (70.4)
Intracranial hemorrhage, including SAH/TBI 8 (3.2)	Stroke, 6 (66.7) Seizure, 1 (11.1) Headache, 1 (11.1)	CCT, 9 (100) 12-Lead ECG, 2 (22.2)	Anticonvulsants, 1 (11.1)	2 (22.2)	Total, 6 (75.0) AMU, 4 (50.0) Tertiary care center, 1 (12.5) Left at home, 1 (12.5)
Other neurological 27 (10.8)	Stroke, 21 (77.8) Headache, 2 (7.4) Unconsciousness, 2 (7.4) Pandemic, 1 (3.7) Breathing problems, 1 (3.7)	CCT, 23 (85.2) 12-Lead ECG 7 (25.9) Electroencephalography, 1 (3.7) Chest X-ray, 1 (3.7) Lung ultrasound, 1 (3.7)	Aspirin, 10 (37.0) Antihypertensive treatment, 2 (7.4) Antiemetic treatment, 3 (11.1) Anticonvulsants, 1 (3.7)	3 (11.1)	Total, 24 (88.9) Stroke unit, 4 (14.8) AMU, 5 (18.5) Left at home, 15 (55.6)
Other medical 62 (24.8)	Stroke, 38 (61.3) Unconsciousness, 8 (12.9) Chest pain, 6 (9.7) Pandemic, 3 (4.8) Headache, 3 (4.8) Breathing problems, 1 (1.6) Seizure, 1 (1.6) Falls, 1 (1.6) Overdose, 1 (1.6)	CCT, 36 (58.1) 12-Lead ECG, 25 (40.3) Ultrasound, 2 (3.2) Electroencephalography, 1 (1.6) Chest X-ray, 1 (1.6)	ACS treatment, 6 (9.7) Fluids, 4 (6.5) Antibiotics, 2 (3.2) Anticonvulsants, 2 (3.2) Sepsis Six bundle, 1 (1.6) Thrombolysis, 1 (1.6) TIA medication, 1 (1.6)	17 (27.4)	Total, 46 (74.2) Stroke unit, 9 (14.5) AMU, 10 (16.1) Left at home, 27 (43.5)

ACS indicates acute coronary syndrome; A&E, accident and emergency department; AMU, acute medical unit; CCT, cranial computed tomography; IVT, intravenous thrombolysis with alteplase; MSU, mobile stroke unit; SAH, subarachnoid hemorrhage; and TBI, traumatic brain injury.

*Further management included referral to the patient's general practitioner for follow-up care and prescription of medications.

†Seven patients with diagnosis of ischemic stroke were not conveyed to hospital but received a transient ischemic attack (TIA) clinic appointment within <12 hours and safety-netting. The reasons were refusal of hospital admission (n=2), onset of symptoms weeks ago (n=2), minor stroke (facial numbness while lack of bed capacity during pandemic) (n=1), 2-day history sensory symptoms in line with stroke mimicking disease (pins and needles only) (n=1), and palliative care pathway with advanced decision against hospital treatment (n=1).

Reduction of Admissions to ED

On the basis of the prehospital diagnostic clarification, ED admission was avoided for 215 Hybrid-MSU patients (86.0%).

A total of 116 (46.4%) patients could be left home, ie, with safety netting (n=31 [12.4%]), with referral to general practitioners (n=49 [19.6%]), and with appointment at outpatient clinics (n=36 [14.4%]). For comparison, patients treated with conventional ambulance crews with the same dispatch codes during the same period and in the whole catchment area (5 ambulance stations), 35.7% of the patients (1398 patients of a total of 3916 patients) were not transported to hospital; thus, ≈10% less than with the Hybrid-MSU. A clear benefit could be identified for the group of multimorbid

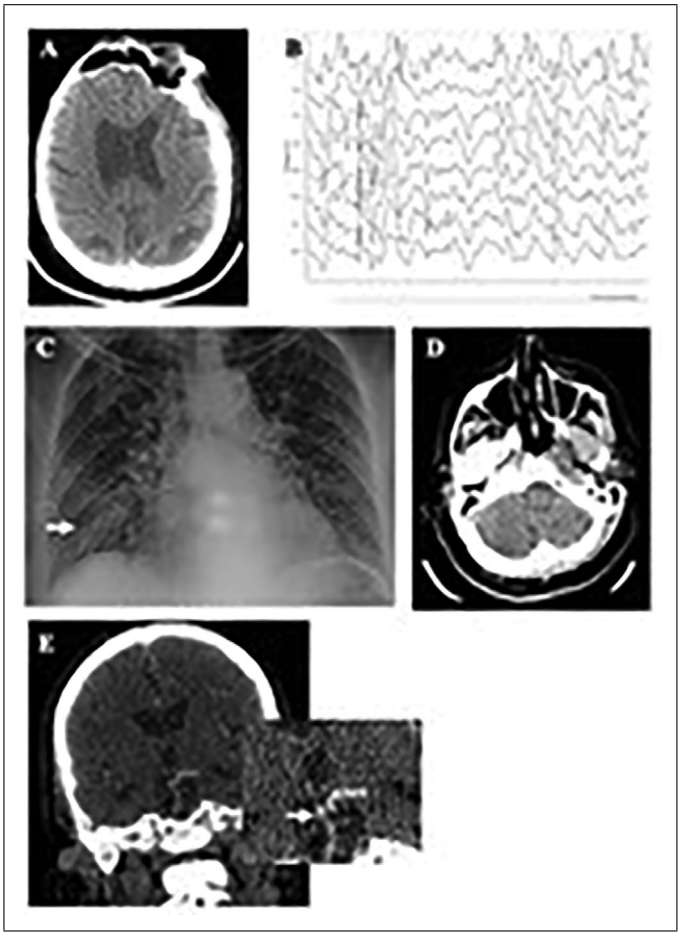

Figure 1. Examples of emergencies treated in a hybrid-mobile stroke unit (MSU) with a widened indication spectrum. (A) Anticoagulated patient with fall. An 86-year-old patient with Parkinson disease and dementia treated with warfarin for atrial fibrillation was found on the floor (Glasgow Coma Scale [GCS] score, 15). Findings from the prehospital computed tomography (CT) scan (A) ruled out an intracranial bleed or a fracture. Laboratory analysis showed an international normalized ratio (INR) of 3.0 and a CRP (C-reactive protein) concentration of 27 mg/L. The patient was left at home with referral to his general practitioner. (B) Patient with status epilepticus. A 34-year-old man was found unresponsive to questions and commands. Although the results of a CT scan were normal, prehospital electroencephalography (B) showed status epilepticus. After treatment with 2 g of intravenous levetiracetam, the patient's condition rapidly improved, and he was triaged to the acute medical assessment unit for additional care. (C) Patient with pneumonia. A 70-year-old woman with the dispatch code "stroke" was found unable to stand, with a severe headache and vomiting. Clinical examination found crepitations in the right lung and a respiratory rate of 20 breaths per minute (GCS score, 15). Her temperature was 39.7°C and CRP concentration was 133 mg/L. Findings from a cranial CT performed because of the severe headache and anticoagulation treatment was normal, but results from a chest radiograph showed a right lower zone consolidation and basal inflammatory changes (C, arrow). The prehospital diagnosis was pneumonia (Confusion, Urea nitrogen, Respiratory rate, Blood pressure, 65 years of age and older [CURB-65] score was 3). The patient was treated with intravenous benzylpenicillin and triaged to the acute medical assessment unit, from which she was discharged 1 day later. (D) Patient with basilar occlusion. An 81-year-old man with dispatch code "chest pain" was found to be pale and sweaty. A 12-lead ECG yielded normal findings. Gradually, dysarthria, a left-sided facial droop, and severe gait ataxia developed (GCS score, 15). Whereas a noncontrast CT scan ruled out hemorrhage or demarcated infarct, prehospital CT angiography detected a thrombus in the basilar artery (D, arrow). The patient was treated with intravenous alteplase on scene and was triaged to the nearest thrombectomy center with prenotification. After 11 days, the patient was discharged home with incomplete residual left-sided hemianopia. CSC indicates comprehensive stroke center; ED, emergency department; and EMS, emergency medical services.

patients (n=16) with fall on head, who were treated with anticoagulation. The on-scene diagnostic assessment and exclusion of traumatic brain injury enabled them to safely stay at home or in their nursing home instead of getting transported to the hospital for brain imaging examination. Nonconveyance to hospital differed for these patients most prominently with an MSU nonconveyance rate of 71%, compared with a nonconveyance rate of conventional ambulances of 38%. Of all patients with dispatch code stroke, who participated in the study, 46% of MSU-treated patients versus 34% of conventional ambulance–treated patients were left at home.

In addition, ED was bypassed in a further 99 patients (39.6%) treated by the MSU by direct hand-over to the required specialized wards, ie, a stroke unit (n=61

Table 2. Emergency Codes and Prehospital Treatment Options of the Hybrid-MSU

Emergency codes	Prehospital assessment	Potential diagnoses	Potential implications for treatment and triage
Seizures	CCT, EEG, ECG, blood tests (electrolytes, kidney, and infection markers)	(Non)convulsive status epilepticus, encephalopathy (metabolic derangement), brain tumor, stroke, functional	Specific anticonvulsive agents (levetiracetam), triage decision-making
Falls	CCT, coagulation parameter	Intracranial hemorrhage, traumatic brain injury	Triage decision-making
Headache	CCT, blood analysis (including infection markers)	Intracranial hemorrhage, migraine, sinusitis	Triage decision-making, symptomatic treatment
Stroke	CCT, CT angiography, CT perfusion, EEG, ECG, blood tests (including full blood count, coagulation, and infection markers)	Ischemic vs. hemorrhagic stroke, large-vessel occlusion, stroke-mimicking diseases (Bell palsy, seizures/Todd paresis, infection)	Thrombolysis, anticonvulsive agents, antibiotics, fluids, triage decision-making
Unconsciousness	CCT, CT angiography, EEG, ECG, blood tests (renal and infection markers, blood gases, lactate, NT-proBNP, TropT, toxicology)	Seizures, stroke (including basilar artery occlusion), intoxication, dehydration, renal, failure, electrolyte dysbalance	Intravenous thrombolysis, anticonvulsive treatment, fluids, triage decision-making for required level of care
Treatable infection	Chest radiography, ultrasonography, blood tests (including CRP, procalcitonin, full blood count, renal markers, lactate)	Sepsis, infection of chest, urinary tract, skin	Sepsis Six bundle, including antibiotics, fluids, triage decision-making
Breathing problems	Chest radiography, ultrasonography, blood tests (including CRP, procalcitonin, full blood count, renal markers, blood gases, lactate, NT-proBNP, D-dimer)	COPD, asthma, PE, cardiac failure, pneumothorax	Aerogen advanced nebulizer treatment, magnesium, antibiotics, Sepsis Six bundle, triage decision-making

CCT indicates cerebral computed tomography; COPD, chronic obstructive pulmonary disease; CRP, C-reactive protein; INR, international normalized ratio; NT-proBNP, N-terminal pro-B-type natriuretic peptide; PE, pulmonary embolism; and TropT, Troponin T.

[24.4%]), to an acute medical unit (n=35 [14.0%]), to a catheter laboratory (n=2 [0.8%]), and to a neurosurgery department (n=1 [0.4%]).

Emergency Management Metrics and Safety

Associated with treatment administered already on scene, emergency management metrics of the Hybrid-MSU group were higher than those of the control group with regard to call-to-hospital arrival times: Hybrid-MSU group (median, 89 minutes; IQR, 77–117 minutes) and control group (76 minutes; IQR, 61–101 minutes) ($P<0.001$). No patient died during Hybrid-MSU interventions. One Hybrid-MSU patient and 4 control patients died during their stay in hospital.

DISCUSSION

The current study shows the feasibility and potential benefits of an MSU with a widened indication spectrum. Its multifunctionality did not only provide treatment of additional cerebral emergencies but also to act alone, without the adjunctive EMS support usually required by MSUs.

Dispatch codes and final diagnoses diverged considerably: 51% of dispatches coded as stroke were found to be emergencies other than stroke, whereas 20% of dispatches for other codes were found to be acute stroke, a fact arguing against the use of monopurpose MSUs. The opened indication spectrum of the Hybrid-MSU allowed treatment or rational triage of a wide range of time-sensitive emergencies beyond stroke in the prehospital setting, such as seizure, fall with traumatic head injury, acute headache, infection, or unconsciousness. According to the generally accepted "golden hour" concept, earlier delivery of emergency treatment is generally expected to translate to better clinical outcomes.

Avoidable hospital admissions do not only contribute to overcrowding of strained EDs[14] and high costs but also put elderly patients at risk for hospital-related complications, such as delirium, depression, falls, skin ulcers, nosocomial infections, and poor quality of life.[15] Prehospital diagnosis allows for diagnosis-based decision-making about whether hospitalization could be avoided, with an additional ≈10% of patients left at home as compared with data of all patients who were conventionally treated in the same region, during the same time and with the same spectrum of dispatch codes. In addition, a further ≈40% of the patients could be directly handed over to the required department, thereby bypassing the ED.

Interestingly, benefits of the Hybrid-MSU for prehospital treatment and triage were mainly seen for cerebral emergencies. This included specific anticonvulsive treatment of patients with seizures, who had an indication for long-term antiepileptic treatment (11 cases)

or patients with otherwise nondiagnosed nonconvulsive seizures in 4 cases. Additionally, by administration of levetiracetam rather than the nonspecific benzodiazepine diazepam, negative side effects such as sedation and potential respiratory failure could be avoided. A clinically important benefit was exclusion of hemorrhage in the anticoagulated falling patients (n=16), who could be left in the ambulatory setting. This finding may be explained by the specifically high relevance of onboard imaging for cerebral emergencies.

In contrast, a benefit for cardiac or pulmonary emergencies from Hybrid-MSU could not be proven. Although patients with acute coronary syndrome were treated, their treatments did not differ from those by conventional ambulances; ie, quantification of cardiac laboratory markers in the field did not allow management in the community because of the necessity of their follow-up quantification. The number of patients with diagnosed pulmonary disease was too low to identify a potential benefit of a Hybrid-MSU.

A total of 20% of all patients with hospital-confirmed acute ischemic stroke were not dispatched as suspected stroke patients. These were mainly patients with posterior circulation symptoms. Of the 15 stroke patients, who received IVT, 20% (n=3) were not dispatched as suspected stroke but with codes for fall, unconsciousness, and chest pain, respectively. This finding underlines the importance of better dispatch algorithms for patients with acute stroke to minimize the risk of them being missed or having delayed access to acute treatments. At the same time, this high rate of strokes among patients with codes other than stroke supports the usefulness of a Hybrid-MSU in timely delivery of acute stroke treatment to them.

In the majority of the cases (n=168 [67%]), the Hybrid-MSU was dispatched to patients with suspected stroke. The ambulance operated in a catchment area with a radius of 20 miles around the ambulance station at which it was based. Despite this small radius, traveling times to cross this catchment area were >40 minutes because of the largely rural geography. Patients with suspected stroke were dispatched as category 2 emergencies with an average response time of 18 minutes. Even without being bound by dispatches for other disease categories, the Hybrid-MSU would not have been dispatched to all patients with suspected stroke within its working hours because of the geographical conditions.

In conclusion, the current study indicates the feasibility and the potential benefits of a wide-spectrum MSU for prehospital treatment and triage that covers cerebral emergencies beyond stroke. For example, in nonmetropolitan regions, this multifunctionality and act-alone capability could be a key for rational integration of MSUs into regular health care.

ARTICLE INFORMATION

Received May 19, 2022; Accepted August 17, 2022

Affiliations

Department of Neurology, Saarland University Medical Center, Homburg, Germany (K.F., A.S., M.L., V.W., M.B., F.M., S.W.); Imaging Science and Technology, School of Medicine, University of Dundee, Dundee, UK (I.Q.G.); East of England Ambulance Service NHS Trust, Melbourn, UK (D.J.P., R.M., D.W., B.W., R.M., R.W., S.W.); East Suffolk and North Essex NHS Foundation Trust, Ipswich, UK (S.A., S.W.); Mid and South Essex NHS Foundation Trust, Southend-on-Sea, UK (S.P., D.D., J.T.); Norfolk and Norwich University Hospital NHS Foundation Trust, Norwich, UK (A.C.); Barts Health NHS Trust, London, UK (A.C.); Institute for Medical Biometry, Epidemiology and Medical Informatics, Saarland University, Campus Homburg, Saarland, Germany (S.W.); Institute of Clinical Chemistry, Laboratory Medicine and Transfusion Medicine, Nuremberg General Hospital, Paracelsus Medical University, Nuremberg, Germany (T.B.)

Acknowledgments

We thank all study participants and colleagues from the East of England Ambulance Service and East Suffolk and North Essex NHS Foundation Trust, Ipswich hospital for their support of this study.

Sources of Funding

A grant was provided by the European Stroke Research Foundation (Basel, Switzerland).

Disclosures

None.

Supplemental Materials

supporting information
Members of the Hybrid-MSU working group in alphabetical order

REFERENCES

1. Gainza-Lein M, Sanchez Fernandez I, Jackson M, Abend NS, Arya R, Brenton JN, Carpenter JL, Chapman KE, Gaillard WD, Glauser TA, et al. Association of time to treatment with short-term outcomes for pediatric patients with refractory convulsive status epilepticus. *JAMA Neurol*. 2018;75:410-418.
2. Kamppi L, Mustonen H, Kotisaari K, Soinila S. The essence of the first 2.5 h in the treatment of generalized convulsive status epilepticus. *Seizure*. 2018;55:9-16.
3. Powers WJ, Rabinstein AA, Ackerson T, Adeoye OM, Bambakidis NC, Becker K, Biller J, Brown M, Demaerschalk BM, Hoh B, et al. 2018 Guidelines for the early management of patients with acute ischemic stroke: A guideline for healthcare professionals from the American Heart Association/American Stroke Association. *Stroke*. 2018;49:e46-e110.
4. Marehbian J, Muehlschlegel S, Edlow BL, Hinson HE, Hwang DY. Medical management of the severe traumatic brain injury patient. *Neurocrit Care*. 2017;27:430-446.
5. Levy MM, Evans LE, Rhodes A. The surviving sepsis campaign bundle: 2018 update. *Crit Care Med*. 2018;46:997-1000.
6. O'Gara PT, Kushner FG, Ascheim DD, Casey Jr DE, Chung MK, de Lemos JA, Ettinger SM, Fang JC, Fesmire FM, Franklin BA, et al. 2013 ACCF/AHA guideline for the management of ST-elevation myocardial infarction: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines. *Circulation*. 2013;127:e362-425.
7. O'Keeffe C, Mason S, Jacques R, Nicholl J. Characterising non-urgent users of the emergency department (ED): a retrospective analysis of routine ED data. *PLoS ONE*. 2018;13:e0192855.
8. Fassbender K, Walter S, Liu Y, Muehlhauser F, Ragoschke A, Kuehl S, Mielke O. "Mobile stroke unit" for hyperacute stroke treatment. *Stroke*. 2003;34:e44.
9. Walter S, Kostpopoulos P, Haass A, Helwig S, Keller I, Licina T, Schlechtriemen T, Roth C, Papanagiotou P, Zimmer A, et al. Bringing the

hospital to the patient: first treatment of stroke patients at the emergency site. *PLoS ONE*. 2010;5:e13758.
10. Walter S, Kostopoulos P, Haass A, Keller I, Lesmeister M, Schlechtriemen T, Roth C, Papanagiotou P, Grunwald I, Schumacher H, et al. Diagnosis and treatment of patients with stroke in a mobile stroke unit versus in hospital: a randomised controlled trial. *Lancet Neurol*. 2012;11:397-404.
11. Helwig SA, Ragoschke-Schumm A, Schwindling L, Kettner M, Roumia S, Kulikovski J, Keller I, Manitz M, Martens D, Grün D, et al. Prehospital stroke management optimized by use of clinical scoring vs mobile stroke unit for triage of patients with stroke: a randomized clinical trial. *JAMA Neurol*. 2019;76:1484-1492.
12. Ebinger M, Siegerink B, Kunz A, Wendt M, Weber JE, Schwabauer E, Geisler F, Freitag E, Lange J, Behrens J, et al. Association between dispatch of mobile stroke units and functional outcomes among patients with acute ischemic stroke in Berlin. *JAMA*. 2021;325:454-466.
13. Grotta JC, Yamal JM, Parker SA, Rajan SS, Gonzales NR, Jones WJ, Alexandrov AW, Navi BB, Nour M, Spokoyny I, et al. Prospective, multicenter, controlled trial of mobile stroke units. *N Engl J Med*. 2021;385:971-981.
14. Morley C, Unwin M, Peterson GM, Stankovich J, Kinsman L. Emergency department crowding: a systematic review of causes, consequences and solutions. *PLoS ONE*. 2018;13:e0203316.
15. Dwyer R, Gabbe B, Stoelwinder JU, Lowthian J. A systematic review of outcomes following emergency transfer to hospital for residents of aged care facilities. *Age Ageing*. 2014;43:759-766.