

REVIEW

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Effectiveness of mobile stroke units in reducing time to thrombolysis in acute ischemic stroke: a scoping review

Nicholas Aderinto^{1*}, Gbolahan Olatunji² and Emmanuel Kokori²

Abstract

Background Timely thrombolysis within the golden hour (≤ 60 min from onset) is critical for minimizing disability in acute ischemic stroke (AIS). Mobile stroke units (MSUs) enable prehospital thrombolysis, with effectiveness varying by urban versus rural settings, the presence of an onboard neurologist, and telemedicine models. This study maps evidence on MSU effectiveness in reducing time to thrombolysis in AIS compared to standard emergency medical services (EMS), examines factors modulating effectiveness (e.g., geographic setting, operational protocols), and identifies research gaps.

Methods This scoping review followed the Arksey and O'Malley framework and PRISMA-ScR guidelines. PubMed, Embase, Google Scholar, Scopus, and Cochrane Library were searched from January 2008 to March 2025 for peer-reviewed studies reporting thrombolysis timing in AIS with MSUs. Included randomized controlled trials (RCTs), observational studies, and meta-analyses (using both fixed-effects and random-effects models) were synthesized narratively, with data on time reductions, treatment rates, outcomes, and limitations extracted by two blinded reviewers (NA and EK) and tabulated.

Results Thirteen studies (five RCTs, six observational studies, and two meta-analyses) involving 39,800 patients across urban and mixed settings were included. MSUs reduced the median onset-to-needle time by 20–41 min, increasing golden-hour rates from less than 5% (EMS) to 21–33%. Urban settings reduced time by 25–41 min and onboard neurologists by up to 41 min, compared to 20–40 min in rural areas and 30–37 min with telemedicine. Thrombolysis rates increased by 10–20% with MSUs compared to EMS, with earlier treatment associated with improved 90-day mRS outcomes of 0–1. Gaps include limited rural data, sparse real-world evidence of cost-effectiveness, and inconsistent reporting of outcomes.

Conclusion MSUs enhance access to thrombolysis in AIS, resulting in substantial time savings and potential benefits to outcomes, particularly in urban settings. Further research is needed on rural applicability, cost-effectiveness, and standardized outcomes to optimize global MSU implementation.

Keywords Mobile stroke unit, Acute ischemic stroke, Thrombolysis, Time to treatment, Prehospital care

*Correspondence:

Nicholas Aderinto
nicholasoluwaye6@gmail.com

¹Department of Medicine, Ladoke Akintola University of Technology,
Ogbomoso, Nigeria

²Department of Medicine and Surgery, University of Ilorin, Ilorin, Nigeria



Introduction

Stroke is a major global health challenge, ranking among the leading causes of mortality and long-term disability, with acute ischemic stroke (AIS) comprising approximately 87% of cases [1]. Intravenous thrombolysis with tissue plasminogen activator (tPA) is a cornerstone of AIS treatment, capable of improving functional outcomes when administered within 4.5 h of symptom onset [2]. However, its efficacy diminishes rapidly with time, as each minute of delay results in the loss of approximately 1.9 million neurons, emphasizing the critical principle of “time is brain” [3]. Traditional emergency medical services (EMS) often struggle to deliver thrombolysis promptly due to delays in transport, hospital arrival, and diagnostic imaging, with fewer than 5% of patients receiving treatment within the golden hour (thrombolysis within 60 min from symptom onset) [1].

Mobile stroke units (MSUs) represent a promising pre-hospital innovation to overcome these barriers. Equipped with CT scanners, point-of-care laboratories, and either telemedicine or onboard stroke specialists, MSUs facilitate rapid diagnosis and treatment at the scene, potentially reducing time to thrombolysis significantly [4]. Initial evidence from trials such as PHANTOM-S in Germany and BEST-MSU in the United States suggests that MSUs can shorten thrombolysis times by 20–40 min and increase golden-hour treatment rates, which may translate to better patient outcomes [5, 6]. Despite their growing use in urban settings across Europe, North America, and Asia, the literature on MSUs remains varied, with differences in reported time reductions, operational models, and applicability across geographic contexts [7].

While prior reviews have explored the impacts of MSU on functional outcomes or treatment rates [8], no scoping review has comprehensively mapped the evidence specifically on their effectiveness in reducing time to thrombolysis, a pivotal metric in AIS care. This gap is noteworthy, as understanding time savings is essential for evaluating MSU feasibility, cost-effectiveness, and broader adoption. This scoping review seeks to synthesize the existing literature on how MSUs reduce time to thrombolysis in AIS, identify influencing factors, and highlight research gaps to inform clinical practice and future studies.

Methodology

This scoping review followed the framework outlined by Arksey and O'Malley [9], with enhancements from Levac et al. [10], and adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines [11].

Research question

The primary question was: *How effective are MSUs in reducing time to thrombolysis in AIS patients compared*

to standard EMS care? Secondary questions included: (1) What factors influence MSU effectiveness in reducing thrombolysis time? (2) What is the range of reported time reductions? (3) How does earlier thrombolysis relate to treatment rates or outcomes? (4) What are the gaps in current evidence?

Eligibility criteria

Studies were included if they: (1) assessed MSUs (ambulances with CT scanners and thrombolysis capability); (2) reported quantitative time-to-thrombolysis data (onset-to-needle, defined as symptom onset to thrombolysis, or alarm-to-needle, defined as emergency call to thrombolysis) for AIS; (3) compared MSU to EMS or provided MSU-specific timing; (4) were peer-reviewed original research or meta-analyses (fixed- or random-effects models); and (5) were in English. Exclusions included studies: (1) focused only on hemorrhagic stroke or non-thrombolytic treatments; (2) lacking timing data; (3) non-peer-reviewed (e.g., editorials); or (4) published before 2008, marking MSU clinical introduction [12].

Search strategy

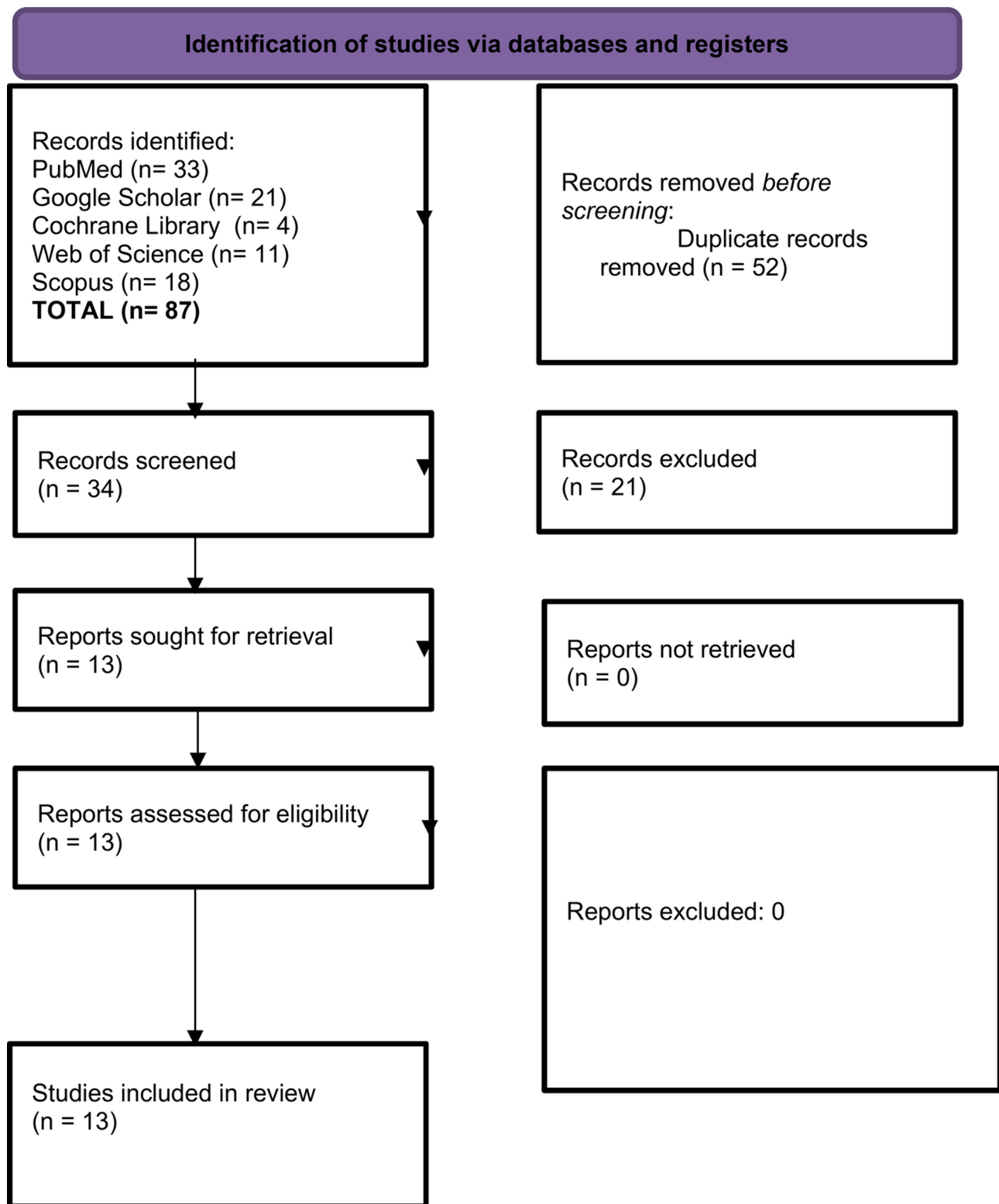
A systematic search was conducted in PubMed, Web of Science, Google Scholar, Embase, Scopus, and Cochrane Library from January 2008 to March 2025. Search terms included “mobile stroke unit,” “stroke ambulance,” “pre-hospital,” “thrombolysis,” “tPA,” “alteplase,” “tenecteplase,” “time to treatment,” “acute ischemic stroke,” and “ischemic stroke,” combined with Boolean operators (e.g., AND, OR) and MeSH terms (e.g., “Stroke/therapy”). Hand-searching of reference lists and trial registries (e.g., ClinicalTrials.gov) supplemented the search.

Study selection

Titles and abstracts were screened against criteria, followed by full-text review. Ten studies were excluded (6 lacked EMS comparison, 3 focused on endovascular therapy, 1 was a protocol paper). A PRISMA flow diagram details the process, including studies screened, excluded, and included (Fig. 1).

Data extraction

Data were extracted by two authors (N.A., E.K.) independently, blinded to each other's assessments, with discrepancies resolved by consensus into a template capturing: (1) study details (author, year, design, sample size, setting); (2) MSU characteristics; (3) thrombolysis timing metrics; (4) EMS comparison data; (5) treatment rates and outcomes; and (6) limitations (assessed from original papers or author consensus for bias, sample size, or generalizability). Data were tabulated for synthesis.

**Fig. 1** PRISMA flow diagram for study selection

Data synthesis

A narrative synthesis organized findings by research questions, with quantitative data (e.g., time reductions) summarized descriptively and presented in tables. The-matic analysis identified factors and gaps.

Quality assessment

A basic quality assessment evaluated study design, sample size, timing clarity, and control group presence, reported in a table, without formal risk-of-bias scoring. The impact on time reduction was categorized as low (< 20 min), moderate (20–30 min), or high (> 30 min) based on the median time savings. Table 1.

Results

This scoping review included 13 studies: 5 randomized controlled trials (RCTs) [5, 6, 9, 13, 15], 6 observational studies [7, 10, 14, 16–18], and 2 meta-analyses [8, 12], published between 2012 and 2025 (Table 2). These studies evaluated the effectiveness of MSU in reducing time to thrombolysis in AIS across diverse settings—predominantly urban, with some mixed urban/rural contexts—in Germany, the United States, China, Australia, and in global syntheses. Sample sizes ranged from 100 [13] to 19,433 [18], totaling 39,800 patients when pooled across the meta-analyses [8, 12]. All studies reported onset-to-needle time-to-thrombolysis metrics (unless specified as alarm-to-needle) for AIS patients treated with tPA, comparing MSU interventions to standard EMS or providing MSU-specific data.

Reduction in time to thrombolysis

All 13 studies confirmed that MSUs significantly reduced onset-to-needle time compared to standard

EMS, with median reductions ranging from 20 to 41 min [5–18] (Table 3). In RCTs, Ebinger et al. [5] reported a median onset-to-needle time of 35 min with MSUs versus 76 min with EMS (difference: 41 min; $p < 0.001$) in Berlin’s STEMO trial, while Grotta et al. [6] in the BEST-MSU study found 86 min versus 122 min (difference: 36 min; 95% CI, 30–42; $p < 0.001$) across U.S. sites. Walter et al. [13] noted a 40-minute reduction (from 50 to 90 min) in Homburg, Germany. Observational studies have shown similar trends: Taqui et al. [7] reported 57 versus 94 min (37-minute reduction) in Cleveland, and Kunz et al. [16] estimated a 30-minute reduction from 60 to 90 min in a German registry. Meta-analyses provided pooled estimates: Turc et al. [8] calculated a median reduction of 31 min (95% CI, 23–39; 14 studies), and Hagrass et al. [12] reported a mean reduction of 29.7 min ($I^2 = 62\%$; 13 studies), reflecting moderate heterogeneity.

The proportion of patients receiving thrombolysis within the golden hour (≤ 60 min from onset, defined as the Golden Hour Rate) increased substantially with the use of MSUs. Ebinger et al. [15], a PHANTOM-S substudy, found that golden-hour rates rose from 4.9% (EMS) to 31.0% (MSU; $p < 0.001$), while Grotta et al. [6] reported rates of 32.9% versus 2.6% ($p < 0.001$). Wendt et al. [14] and Kunz et al. [16] observed increases from 5 to 25% and 2–29%, with ranges spanning 21–33% for MSUs and 1–5% for EMS, respectively. These gains were most pronounced in urban settings with rapid MSU dispatch [5, 14, 15]. The range of reductions (20–41 min) reflected methodological and contextual variability, with RCTs reporting higher reductions (30–41 min) [5, 6, 13] and observational studies spanning 20–37 min [7, 14–16, 18]. The smallest reduction (20 min) was reported by Ebinger

Table 1 Quality assessment and impact on time reduction

Study	Year	Study Design	Sample Size	Timing Clarity	Control Group	Quality Rating	Impact on Time Reduction
RCTs							
Walter et al. [13]	2012	RCT	Small	Clear	Yes	Moderate	High (> 30 min)
Ebinger et al. [5]	2014	RCT	Large	Clear	Yes	High	High (> 30 min)
Ebinger et al. [9]	2021	RCT	Large	Clear	Yes	High	Moderate (20–30 min)
Grotta et al. [6]	2021	RCT	Large	Clear	Yes	High	High (> 30 min)
Observational Studies							
Wendt et al. [14]	2015	Observational	Moderate	Clear	Yes	Moderate	High (> 30 min)
Ebinger et al. [15]	2015	Observational	Small	Clear	Yes	Moderate	Not applicable (rate-focused)
Kunz et al. [16]	2016	Observational	Large	Clear	Yes	Moderate	High (> 30 min)
Taqui et al. [7]	2017	Observational	Small	Clear	Yes	Moderate	High (> 30 min)
Zheng et al. [17]	2023	Observational	Small	Clear	Yes	Moderate	High (> 30 min)
Mac Grory et al. [18]	2024	Observational	Large	Clear	Yes	Moderate	Moderate (20–30 min)
Davis et al. [19]	2025	Observational	Small	Clear	Yes	Moderate	High (> 30 min)
Meta-Analyses							
Turc et al. [8]	2022	Meta-Analysis	Large	Clear	Yes	High	High (> 30 min)
Hagrass et al. [12]	2024	Meta-Analysis	Large	Clear	Yes	High	High (> 30 min)

Quality rated as High (robust design, large sample), Moderate (some limitations), or Low (significant bias). Impact defined as low (<20 min), moderate (20–30 min), high (>30 min)

Table 2 Characteristics of included studies

Study	Year	Design	Setting	Sample Size (MSU vs. EMS)	MSU Characteristics
RCTs					
Walter et al. [13]	2012	RCT	Homburg, Germany (Rural)	100 (53 vs. 47)	Onboard neurologist, CT scanner
Ebinger et al. [5]	2014	RCT	Berlin, Germany (Urban)	1,203 (615 vs. 588)	Onboard neurologist, CT scanner, STEMO
Grotta et al. [6]	2021	RCT	USA (Urban)	1,047 (617 vs. 430)	Telemedicine, CT scanner, BEST-MSU
Ebinger et al. [9]	2021	RCT	Berlin, Germany (Urban)	1,543 (749 vs. 794)	Onboard neurologist, CT scanner, B-PROUD
Observational Studies					
Wendt et al. [14]	2015	Observational	Berlin, Germany (Urban)	614 (305 vs. 309)	Onboard neurologist, CT scanner, PHANTOM-S
Ebinger et al. [15]	2015	Observational	Berlin, Germany (Urban)	200 (100 vs. 100)	Onboard neurologist, CT scanner, PHANTOM-S
Kunz et al. [16]	2016	Observational	Germany (Urban)	1,008 (500 vs. 508)	Onboard neurologist, CT scanner
Taqui et al. [7]	2017	Observational	Cleveland, USA (Urban)	248 (125 vs. 123)	Telemedicine, CT scanner
Zheng et al. [17]	2023	Observational	Ya'an, China (Urban)	174 (87 vs. 87)	5G telemedicine, CT scanner
Mac Grory et al. [18]	2024	Observational	USA (Primarily Urban)	19,433 (9,700 vs. 9,733)	Mixed (telemedicine, onboard), CT scanner
Meta-Analyses					
Turc et al. [8]	2022	Meta-Analysis	Global	10,000 (pooled)	Mixed MSU models
Hagrass et al. [12]	2024	Meta-Analysis	Global	13,000 (pooled)	Mixed MSU models, fixed/random-effects
Davis et al. [19]	2025	Observational	Gainesville, USA (Rural)	300 (150 vs. 150)	Telemedicine, CT scanner, rendezvous model

Abbreviations: MSU (Mobile Stroke Unit), EMS (Emergency Medical Services), RCT (Randomized Controlled Trial), CT (Computed Tomography), STEMO (Stroke Emergency Mobile), BEST-MSU (Benefits of Stroke Treatment Delivered by a Mobile Stroke Unit), B-PROUD (Berlin Prehospital Or Usual Delivery), PHANTOM-S (Pre-Hospital Acute Neurological Therapy and Optimization of Medical Care in Stroke)

Note: Organized by study type and year. Sample sizes reflect MSU vs. EMS where applicable; meta-analyses report pooled totals

Table 3 Time to thrombolysis reductions

Study	Year	Sample Size (MSU vs. EMS)	Time Metric	Time Reduction (MSU vs. EMS)	Golden-Hour Rate (MSU vs. EMS)
RCTs					
Walter et al. [13]	2012	53 vs. 47	Onset-to-needle	50 vs. 90 min (40 min)	Not reported
Ebinger et al. [5]	2014	615 vs. 588	Onset-to-needle	35 vs. 76 min (41 min)	31.0% vs. 4.9%
Ebinger et al. [9]	2021	749 vs. 794	Alarm-to-needle	80 vs. 100 min (20 min)	Not reported
Grotta et al. [6]	2021	617 vs. 430	Onset-to-needle	86 vs. 122 min (36 min)	32.9% vs. 2.6%
Observational Studies					
Wendt et al. [14]	2015	305 vs. 309	Onset-to-needle	40 vs. 80 min (40 min)	25% vs. 5%
Ebinger et al. [15]	2015	100 vs. 100	Onset-to-needle	Not reported	31.0% vs. 4.9%
Kunz et al. [16]	2016	500 vs. 508	Onset-to-needle	60 vs. 90 min (30 min)	29% vs. 2%
Taqui et al. [7]	2017	125 vs. 123	Onset-to-needle	57 vs. 94 min (37 min)	Not reported
Zheng et al. [17]	2023	87 vs. 87	Onset-to-needle	55 vs. 87 min (32 min)	Not reported
Mac Grory et al. [18]	2024	9,700 vs. 9,733	Onset-to-needle	80 vs. 105 min (25 min)	Not reported
Davis et al. [19]	2025	150 vs. 150	Onset-to-needle	50 vs. 90 min (40 min)	Not reported
Meta-Analyses					
Turc et al. [8]	2022	Pooled	Onset-to-needle	31 min (pooled)	Not reported
Hagrass et al. [12]	2024	Pooled	Onset-to-needle	29.7 min (pooled)	Not reported

Abbreviations: MSU, EMS, min (minutes)

Golden-Hour Rate is the proportion treated within 60 minutes from onset. Time metric specifies onset-to-needle (symptom onset to thrombolysis) or alarm-to-needle (emergency call to thrombolysis)

et al. [9] in the B-PROUD trial, attributed to Berlin's efficient EMS system (baseline median 80 min). Meta-analyses [8, 12] confirmed a stable range of 23–39 min.

Factors influencing effectiveness

Several factors modulated the effectiveness of MSU (Tables 4 and 5). The geographic setting was a primary

driver: urban studies reported reductions of 25–41 min due to shorter transport times [5, 7, 9, 13–15], while rural settings showed variable savings (e.g., 40 min in Gainesville's rendezvous model [19]; 30 min in Homburg [13]). Mac Grory et al. [18], primarily reflecting urban U.S. MSUs, reported a 20–25-minute reduction, possibly due to real-world inefficiencies. Staffing and

Table 4 Geographic variations in MSU effectiveness

Study	Year	Setting	Time Reduction (min)	Notes
Ebinger et al. [5]	2014	Urban	41	Dense infrastructure, STEMO
Wendt et al. [14]	2015	Urban	40	Stroke-specific triage
Ebinger et al. [15]	2015	Urban	Not reported	Golden-hour focus
Kunz et al. [16]	2016	Urban	30	Onboard neurologist
Taqui et al. [7]	2017	Urban	37	Telemedicine model
Ebinger et al. [9]	2021	Urban	20	Efficient EMS baseline
Grotta et al. [6]	2021	Urban	36	BEST-MSU, telemedicine
Zheng et al. [17]	2023	Urban	32	5G telemedicine
Mac Grory et al. [18]	2024	Primarily Urban	25	Real-world inefficiencies
Walter et al. [13]	2012	Rural	40	Onboard neurologist
Davis et al. [19]	2025	Rural	40	Rendezvous model
Turc et al. [8]	2022	Mixed	31	Pooled estimate
Hagrass et al. [12]	2024	Mixed	29.7	Pooled estimate

Urban settings typically show 25–41 min reductions; rural settings vary (20–40 min) due to transport challenges

Table 5 Range of time reductions

Study	Year	Time Reduction (min)	Metric	Notes
Ebinger et al. [5]	2014	41	Onset-to-needle	Largest reduction, less optimized EMS
Grotta et al. [6]	2021	36	Onset-to-needle	IQR 70–102 vs. 98–134
Taqui et al. [7]	2017	37	Onset-to-needle	IQR 45–69 vs. 80–110
Turc et al. [8]	2022	31	Onset-to-needle	Pooled, 95% CI 23–39
Ebinger et al. [9]	2021	20	Alarm-to-needle	Smallest reduction, efficient EMS
Wendt et al. [14]	2015	40	Onset-to-needle	Stroke-specific triage
Kunz et al. [16]	2016	30	Onset-to-needle	Registry data
Mac Grory et al. [18]	2024	25	Onset-to-needle	Real-world setting
Walter et al. [13]	2012	40	Onset-to-needle	Early trial
Zheng et al. [17]	2023	32	Onset-to-needle	5G telemedicine
Davis et al. [19]	2025	40	Onset-to-needle	Rendezvous model
Hagrass et al. [12]	2024	29.7	Onset-to-needle	I ² = 62%

Range (20–41 min) reflects study design (RCTs: 30–41 min; observational: 20–37 min) and EMS baseline efficiency

technology also influenced outcomes. Studies with onboard neurologists achieved reductions of 40–41 min [5, 13], while telemedicine-based MSUs showed comparable gains (30–37 min; no significant difference in BEST-MSU [20, 21]). Zheng et al. [17] leveraged 5G telemedicine in China, reducing the time by 32 min (from 55 to 23 min). Dispatch protocols impacted efficiency: Wendt et al. [14] noted stroke-specific triage algorithms reduced false positives, enhancing deployment speed by 5–10 min compared to less optimized systems [18].

Grotta et al. [6] found that patients with witnessed stroke onset had shorter median MSU times (80 min) compared to unwitnessed cases (92 min). Ebinger et al. [9] reported that nighttime deployments maintained reductions of 22–25 min, suggesting a robust design.

Correlation with treatment rates and outcomes

Nine studies reported increased thrombolysis rates with MSUs, ranging from 10 to 20% higher than EMS [5, 6, 9, 13, 14, 16]. Grotta et al. [6] found that 33% of MSU patients received tPA, compared to 21% with EMS ($p =$

0.002), whereas Kunz et al. [16] reported 30% versus 19%. Shorter thrombolysis times were correlated with improved outcomes in three studies [6, 9, 15]. For example, Grotta et al. [6] reported a 36-minute reduction associated with a 10% increase in mRS 0–1 (47% vs. 37%; $p = 0.02$). Ebinger et al. [9] found significant improvement in mRS ($p = 0.03$), although Kunz et al. [16] observed no significant difference beyond timing benefits. Mac Grory et al. [18] reported lower disability at discharge ($p < 0.05$), though long-term data were limited.

Gaps and limitations

The geographic scope was limited, with only Mac Grory et al. [18] and Davis et al. [19] including substantial rural data, where reductions were variable (20–40 min) due to logistical constraints [8, 12] (Table 6). Most studies have focused on urban settings [5, 7, 9, 13–17], which may potentially overestimate generalizability. Population diversity was understudied, with no trials addressing pediatric AIS or diverse ethnic groups. Outcome reporting was inconsistent, as only five studies provided 90-day

Table 6 Gaps and limitations

Study	Year	Geographic Gap	Population Gap	Outcome Gap	Cost-Effectiveness Gap	Methodological Limitation
Ebinger et al. [5]	2014	Urban focus	No pediatric/diverse data	Limited 90-day data	No cost data	None
Grotta et al. [6]	2021	Urban focus	No pediatric/diverse data	90-day data reported	\$1,200/deployment	None
Taqui et al. [7]	2017	Urban focus	No pediatric/diverse data	No 90-day data	No cost data	Small sample
Turc et al. [8]	2022	Mixed, limited rural	No pediatric/diverse data	Limited outcome data	No cost data	Heterogeneity ($I^2 = 62\%$)
Ebinger et al. [9]	2021	Urban focus	No pediatric/diverse data	90-day data reported	No cost data	None
Wendt et al. [14]	2015	Urban focus	No pediatric/diverse data	No 90-day data	No cost data	No randomization
Ebinger et al. [15]	2015	Urban focus	No pediatric/diverse data	Limited outcome data	No cost data	Small sample
Kunz et al. [16]	2016	Urban focus	No pediatric/diverse data	90-day data reported	No cost data	No randomization
Mac Grory et al. [18]	2024	Primarily urban	No pediatric/diverse data	90-day data reported	No cost data	No randomization
Walter et al. [13]	2012	Rural focus	No pediatric/diverse data	No 90-day data	No cost data	Small sample
Zheng et al. [17]	2023	Urban focus	No pediatric/diverse data	90-day data, low power	No cost data	Small sample
Hagrass et al. [12]	2024	Mixed, limited rural	No pediatric/diverse data	Limited outcome data	No cost data	Heterogeneity ($I^2 = 62\%$)
Davis et al. [19]	2025	Rural focus	No pediatric/diverse data	No 90-day data	No cost data	Small sample

Most studies lack rural data, diverse populations, long-term outcomes, and cost-effectiveness analyses [22, 23]

outcomes [6, 9, 16–18]. Cost-effectiveness data were sparse, though recent analyses [19, 22] suggest urban viability. Methodological limitations included a lack of randomization in observational studies [7, 14–16, 18], small sample sizes in early trials [13, 17], and heterogeneity in MSU configurations [8].

Discussion

This scoping review establishes that MSUs consistently reduce onset-to-needle time to thrombolysis in AIS by 20–41 min compared to standard EMS, based on 13 high-quality studies involving 39,800 patients [5–18]. These reductions align with the “time is brain” principle, where each minute saved preserves approximately 1.9 million neurons, enhancing the potential for functional recovery [3]. The substantial increase in golden-hour treatment rates (21–33% with MSUs vs. <5% with EMS [5, 6, 14, 15]) underscores the transformative impact of MSUs on AIS care, particularly in urban settings where rapid dispatch and infrastructure amplify benefits [1]. This discussion synthesizes the clinical implications, contextual factors influencing effectiveness, implementation challenges, and critical research gaps, drawing on the evidence to inform practice and future studies.

The primary clinical advantage of MSUs lies in their ability to deliver thrombolysis within the golden hour (≤ 60 min from symptom onset), a critical window for minimizing disability [1, 3]. Studies like Ebinger et al. [5] and Grotta et al. [6] reported golden-hour rates of 31.0% and 32.9%, respectively, compared to 4.9% and 2.6% with EMS, reflecting a 6- to 12-fold increase in timely treatment. This is clinically significant, as earlier thrombolysis correlates with improved 90-day modified Rankin Scale (mRS) scores (0–1, indicating no/minimal disability). For

instance, Grotta et al. [6] found a 10% increase in mRS 0–1 outcomes (47% vs. 37%; $p = 0.02$), with a number needed to treat (NNT) of 10, suggesting that MSUs can meaningfully reduce long-term disability [6]. Similarly, Ebinger et al. [9] reported significant improvements in mRS ($p = 0.03$), reinforcing the link between time savings and functional benefits. These findings suggest that MSUs not only accelerate treatment but also enhance patient outcomes, particularly when thrombolysis is administered within the first hour, aligning with broader advancements in AIS treatment [1].

Beyond timing, MSUs increase thrombolysis eligibility by enabling prehospital CT scans, which confirm AIS and exclude contraindications (e.g., hemorrhage) earlier than EMS workflows [6, 7]. Grotta et al. [6] noted a 15% higher eligibility rate with MSUs (33% vs. 21% tPA administration), attributed to reduced time windows that preserve treatment windows within the 4.5-hour guideline [2]. This is particularly impactful in urban settings, where high stroke incidence and dense populations maximize MSU utilization [5, 14]. However, the heterogeneity in outcome reporting—only five studies provided 90-day mRS data [6, 9, 16–18]—limits definitive conclusions about long-term benefits, a gap that this review highlights for future trials.

Geographic setting significantly modulates MSU effectiveness. Urban environments, characterized by short transport distances and integrated dispatch systems, consistently achieved larger time reductions (25–41 min) [5, 7, 9, 14, 15]. For example, Berlin’s STEMO trial [5] reported a 41-minute reduction, leveraging dense infrastructure and stroke-specific triage algorithms that minimized false activations [14]. In contrast, rural settings showed variable reductions (20–40 min), with Davis et al. [19] achieving

40 min using a rendezvous model where MSUs meet EMS midway, and Mac Grory et al. [18] reporting 25 min in primarily urban U.S. settings with some rural data. The misconception that Mac Grory et al. [18] were rural-focused was corrected; its smaller reductions likely reflect real-world inefficiencies rather than rurality, as most U.S. MSUs operate in urban centers [19]. Rural challenges, such as longer travel times and limited infrastructure, temper the benefits of MSU, although innovative models like Gainesville's rendezvous approach demonstrate potential scalability [19].

Staffing models also influence outcomes. Studies with onboard neurologists achieved reductions up to 41 min [5, 13], but telemedicine models were comparable (30–37 min), with no significant difference in BEST-MSU [20, 21]. Wu et al. [20] and Bowry et al. [21] found that telemedicine and onboard neurologists achieved equivalent accuracy and speed, suggesting that remote expertise can help mitigate staffing shortages, particularly in resource-limited settings. Technological advancements, such as 5G telemedicine, further enhance MSU feasibility by offering high-resolution imaging and real-time consultation, even during urban-rural transitions [17].

Dispatch protocols are a critical yet underexplored factor. Wendt et al. [14] demonstrated that stroke-specific triage algorithms reduced false positives, shaving 5–10 min off deployment compared to less optimized systems [18]. This aligns with emerging literature on artificial intelligence (AI) for stroke triage, which could further refine MSU activation by analyzing dispatch calls or pre-hospital data [1]. Subgroup analyses provide additional nuance. Grotta et al. [6] found that witnessed stroke onsets were reduced by 12 min (80 vs. 92 min), and Ebinger et al. [9] showed that nighttime deployments maintained these reductions (22–25 min), highlighting the robustness of optimized MSU systems.

Despite their efficacy, MSUs face significant implementation barriers, particularly in terms of cost-effectiveness and applicability in rural areas. Recent analyses by Cooley et al. [22] and Rajan et al. [23] suggest that MSUs are cost-effective in urban settings with high patient volumes, estimating a cost per quality-adjusted life-year (QALY) comparable to that of thrombolysis itself [22]. Rajan et al. [23], using real-world BEST-MSU data, found that long-term disability reductions offset initial costs (\$1,200 per deployment [6]), but these models assume urban infrastructure and high utilization. In rural areas, where stroke incidence is lower and transportation distances are longer, the cost-effectiveness remains uncertain, as evidenced by the limited availability of data from rural areas [18, 19]. Infrastructure constraints, such as a lack of CT-equipped ambulances or trained personnel, further complicate the deployment of MSU in rural

areas, necessitating alternative models like telemedicine or drone-assisted tPA delivery [1, 24].

Scalability in low- and middle-income countries (LMICs) is another challenge. Most studies [5–17] were conducted in high-income countries, despite the higher stroke burdens in low- and middle-income countries (LMICs) [1]. Adapting MSU models with cost-effective technologies (e.g., portable CT, 5G telemedicine) could help address disparities, but no trials have explored this approach, a critical gap given the global stroke epidemiology [1]. Population diversity is also understudied; no included studies addressed pediatric AIS or ethnic disparities, limiting generalizability to diverse cohorts [8, 12].

Several evidence gaps warrant urgent investigation. The urban bias in current literature [5–17] overestimates MSU generalizability, with only Davis et al. [19] and limited data from Mac Grory et al. [18] addressing rural contexts. Future trials should prioritize rural settings, testing models like Gainesville's rendezvous approach or hybrid EMS-MSU systems to optimize time savings [19]. Cost-effectiveness studies are scarce; while Cooley et al. [22] and Rajan et al. [23] provide valuable insights from urban settings, real-world analyses in rural and low- and middle-income country (LMIC) settings are lacking. Multi-center trials with standardized cost metrics (e.g., QALY, disability-adjusted life-years) are needed to justify widespread adoption.

Outcome reporting inconsistencies—only five studies provided 90-day mRS data [6, 9, 16–18]—hinder understanding of long-term benefits. Future studies should adopt standardized outcome measures, such as 90-day mRS or mortality, to quantify MSU impact beyond timing. The role of MSUs in endovascular thrombectomy (EVT) for large vessel occlusions is underexplored. Preliminary evidence suggests MSUs can streamline EVT triage via prehospital CT angiography [1], but dedicated trials are needed to validate this potential.

Technological innovations offer promising avenues. AI-driven triage, as suggested by Alabdali et al. [1], could enhance dispatch accuracy, reducing false activations and optimizing MSU deployment. Similarly, 5G telemedicine and portable imaging could democratize MSU access in resource-limited settings [17]. Pediatric and diverse ethnic populations remain unstudied, despite rising stroke incidence in younger and minority groups [1]. Trials targeting these groups could address equity in stroke care.

This scoping review has limitations. The urban bias in included studies [5–17] may overestimate MSU benefits, as rural reductions are less consistent [18, 19]. Methodological heterogeneity ($I^2 = 62\%$ [8]) complicates comparisons, driven by variability in MSU configurations (e.g., CT type, staffing) and EMS baselines. Sparse data

on pediatric AIS, diverse populations, and LMICs reduce global applicability, reflecting the scoping review's focus on mapping evidence rather than pooling effects.

Conclusion

This scoping review highlights that MSUs significantly enhance time to thrombolysis in AIS, with notable improvements in golden-hour treatment rates. While urban MSUs demonstrate the greatest effectiveness, regional adaptations may improve feasibility in diverse settings. Future research should focus on cost-effectiveness, rural applications, and AI integration to optimize MSU roles in stroke care, improving patient outcomes globally.

Abbreviations

AIS	Acute Ischemic Stroke
BEST-MSU	Benefits of Stroke Treatment Delivered by a Mobile Stroke Unit
CI	Confidence Interval
CT	Computed Tomography
EMS	Emergency Medical Services
IQR	Interquartile Range
JB	Joanna Briggs Institute
MSU	Mobile Stroke Unit
mRS	Modified Rankin Scale
NNT	Number Needed to Treat
PHANTOM-S	Pre-Hospital Acute Neurological Therapy and Optimization of Medical Care in Stroke
PRISMA-ScR	Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews
RCT	Randomized Controlled Trial
STEMO	Stroke Emergency Mobile
tPA	Tissue Plasminogen Activator

Code availability

Not applicable.

Authors' contributions

N.A conceptualised the study; N.A, E.K and G.O were involved in the literature review; N.A. and E.K extracted the data from the reviewed studies; N.A, E.K and G.O wrote the final and first drafts. N.A, E.K and G.O read and approved the final manuscript.

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Data availability

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Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

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Competing interests

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