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Lifetime economic potential of mobile stroke units in acute stroke care: A model-based analysis of the drivers of cost-effectiveness

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Abstract

Background and purpose: To simulate patient-level costs, analyze the economic potential of telemedicine-based mobile stroke units for acute prehospital stroke care, and identify major determinants of cost-effectiveness, based on two recent prospective trials from the United States and Germany.

Methods: A Markov decision model was developed to simulate lifetime costs and outcomes of mobile stroke unit. The model compares diagnostic and therapeutic pathways of ischemic stroke, hemorrhagic stroke, and stroke mimic patients by conventional care or by mobile stroke units. The treatment outcomes were derived from the B_PROUD and the BEST-mobile stroke unit trials and further input parameters were derived from recent literature. Uncertainty was addressed by deterministic and probabilistic sensitivity analyses. A lifetime horizon based on the US healthcare system was adopted to evaluate different cost thresholds for mobile stroke unit and the resulting cost-effectiveness. Willingness-to-pay thresholds were set at 1x and 3x gross domestic product per capita, as recommended by the World Health Organization.

Results: In the base case scenario, mobile stroke unit care yielded an incremental gain of 0.591 quality-adjusted life years per dispatch. Mobile stroke unit was highly cost-effective up to a maximum average cost of 43,067 US dollars per patient. Sensitivity analyses revealed that MSU cost-effectiveness is mainly affected by reduction of long-term disability costs. Also, among other parameters, the rate of stroke mimics patients diagnosed by MSU plays an important role.

Conclusion: This study demonstrated that mobile stroke unit can possibly be operated on an excellent level of cost-effectiveness in urban areas in North America with number of stroke mimic patients and long-term stroke survivor costs as major determinants of lifetime cost-effectiveness.

Keywords

Mobile stroke unit, cost effectiveness, health economics, teleneurology, teleradiology, telehealth, stroke services

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Introduction

Stroke is a leading cause of disability and mortality worldwide, causing a heavy economic burden for aging societies.[1,2] Recent years have seen serial advances in acute stroke intravenous thrombolysis (IVT), including faster in-hospital processes, demonstration that additional mechanical thrombectomy improves outcome, and increasing use of tenecteplase in lieu of alteplase.[3,4] Strong evidence demonstrates that outcome is directly associated with the speed of delivery of reperfusion therapy,[3] hence considerable efforts have been devoted to streamlining preclinical management. In spite of this, a frustratingly low rate of

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only 1.3% of patients receive intravenous tissue plasminogen activator (t-PA) within the first "golden hour" after symptom onset.[5] Many different social, geographical but also structural factors contribute to these delays, emphasizing the urgent need for further improvements.

A groundbreaking new approach to emergency stroke care, the mobile stroke unit (MSU), was first described by Fassbender et al. and ignited a vast resonance worldwide.[6] In a MSU, telemedicine equipment, a head computed tomography (CT) scanner and point-of-care laboratory equipment along with a specialized care team enable sufficient clinical diagnosis and very early treatment initiation on the scene of the acute event. Imaging of the brain allows distinguishing between intracranial hemorrhage (ICH) and ischemic stroke which can present with identical clinical symptoms and laboratory testing rules out coagulation abnormalities so that thrombolytic agents (t-PA) can be safely administered to ischemic stroke patients. As an effect, they can help dissolve the blood clot responsible for stroke and consequently stop further brain damage and avert long-term disability. When administered to patients with intracranial bleeding, t-PA could fatally aggravate ICH. Over the recent years, integration of telemedicine equipment enabled more widespread adoption of the concept while also reducing the costs, as neurologists and radiologists can cover multiple units remotely. The MSU approach has been proven capable of effectively delivering earlier treatment within the first "golden hour" to a majority of patients.[7]

Most recent clinical outcome data from prospective trials in Berlin, Germany (B_PROUD) and in the United States (BEST-MSU, multiple sites) have both demonstrated improved stroke outcomes in urban settings.[8,9] As implementation of the new technology in selected sites is well underway, significant program costs ranging from half a million to 2 million US dollars (USD) annually along with the lack of reimbursement make widespread adoption challenging. As a consequence, the improvements of stroke care associated with MSU utilization may be withheld from many stroke patients worldwide.[10,11] The promising economic potential of delivering early thrombolysis has been shown for other conditions before[12] and over the past decade, early economic analyses have indicated favorable cost-effectiveness of MSU.[13–15] Mainly short-term economic effects of MSU based on reduction of treatment delays were assessed. A German analysis based on extrapolated preclinical data from 2014 predicted avoidance of 18 cases of disability annually per MSU leading to an incremental cost-effectiveness (ICER) ratio of € 32,456/quality-adjusted life year (QALY).[16] Data from the Cleveland MSU in Ohio highlighted that in the short run, avoidance of secondary transports by MSU can save 35% of total program costs,[17] and findings from Melbourne from 2018 indicated that in the short term, 16.90 and 27.90 disability adjusted life years (DALYs) can be avoided by faster access to t-PA and mechanical thrombectomy, respectively.[18] With the stimulation of global interest in MSU by recent clinical evidence on improved functional outcomes, there is an imminent need for further long-term economic analyses.

Assuming a real-world perspective that compares MSU to conventional care and includes stroke mimics and hemorrhagic stroke patients into economic modeling, the goal of this study was to reconfirm the economic value of MSU care based on most recent prospective study-level data from the United States and Germany and to add new insights into major determinants of long-term cost-effectiveness. This framework can be applied to MSU program planning including funding acquisition, calculation of costs and patient numbers as well as for shaping of reimbursement structures.

Methods

Economic model structure

To compare MSU to conventional care from a healthcare perspective, a Markov -decision model was designed following the CHEERS II checklist[19] to simulate long-term costs and outcomes of MSU- and non-MSU-based prehospital stroke care pathways in urban settings based on clinical study-level data from two recent prospective MSU trials.[8,9] Patients later diagnosed with ICH and stroke mimics were also included into short-term economic modeling. Patients classified as "stroke mimics" comprise a heterogeneous group of patients with early symptoms misinterpreted as possible stroke and later diagnosed with alternative conditions such as seizures or hypoglycemia.

The decision model included three possible disease states of the modeled population of suspected stroke patients in urban areas as a ground truth (non-hemorrhagic ischemic stroke/transient ischemic attack (TIA), ICH, or stroke mimics) and included possible therapeutic pathways (Figure 1 and Supplementary S1). For modeling of short-term treatment and outcomes within the first 90 days, the patient entered the model when a stroke was suspected at dispatch. Patients with ischemic stroke/TIA or stroke mimic both could be judged eligible for t-PA treatment and receive thrombolysis. Some ischemic and hemorrhagic stroke patients in the conventional care group required interfacility transfer at rates reported in the literature, whereas none of the patients in the MSU group received secondary transfers due to imaging-supported prehospital assessment.[17,20,21]

Based on a cycle length of 1 year, lifetime outcomes were projected in terms of cumulative QALYs based on the stroke-related utility weights available for different poststroke modified Rankin Scale (mRS) states as reported by the investigators of the source trials.[22] Patients could either stay on the level of disability reported after 90 days, suffer a further stroke resulting in the same or a higher mRS state, or die. Age-specific average background

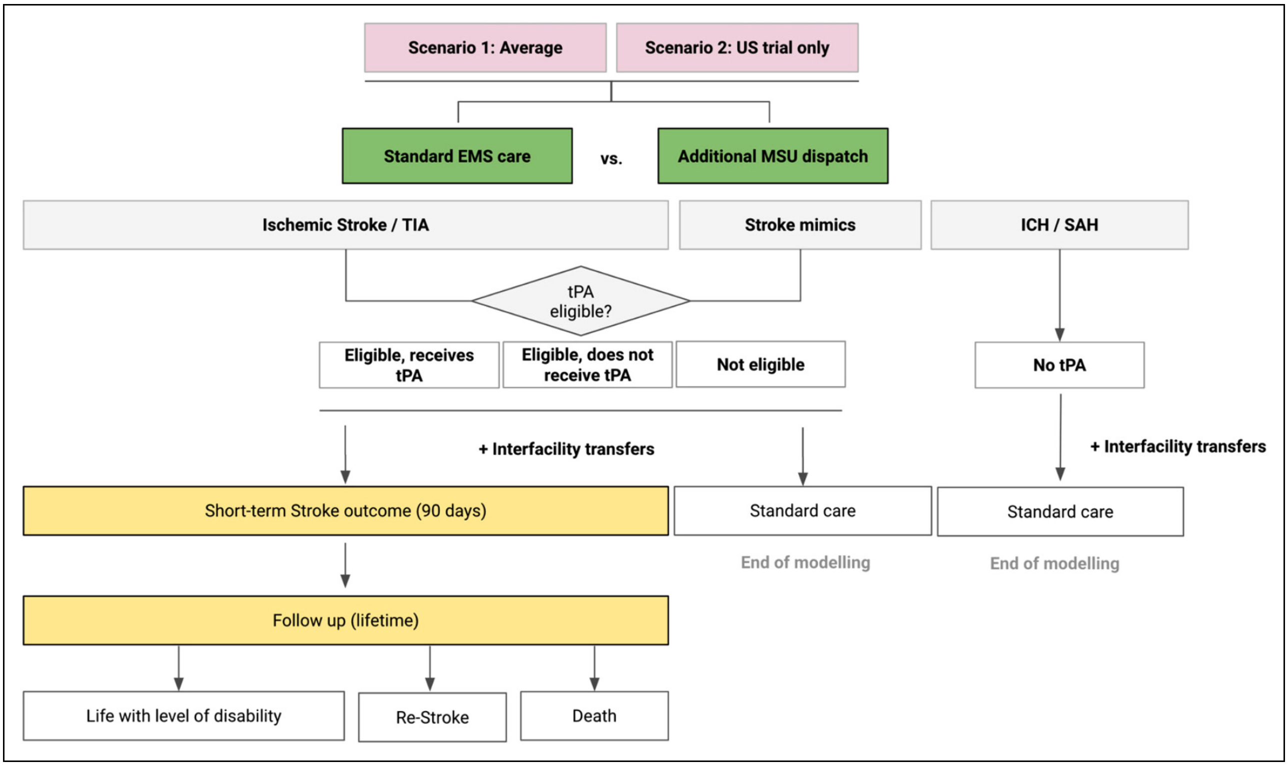

Figure 1. Patient pathway and decision tree. Suspected stroke patients receive care either by regular EMS or by EMS + MSU. The short-run model simulates possible treatment by tissue plasminogen activator (t-PA) and mechanical thrombectomy and accounts for additional secondary transfers of patients. Patients with stroke mimics and intracranial or subarachnoid hemorrhage (ICH or SAH) receive a standard of care and are not included into further modeling. The long-run model simulates the lifelong pathways of stroke patients with a possible level of disability, according to the clinical outcomes reported. Costs and effectiveness (QALYs) are compared for both treatment strategies.
EMS: emergency medical services; MSU: mobile stroke unit; QALYs: quality-adjusted life years.

mortality rates according to the US life tables,[23] excess mortality according to mRS level of index stroke,[24] and time-dependent stroke recurrence rates[25] were included. Additionally, a 1-year and 5-year time horizon was adopted to simulate shorter-term model outcomes. Economic modeling was conducted with TreeAge Pro 2022 (TreeAge, Williamston, MA, USA). More information on the model structure is presented in the supplement.

Multiple scenario approach

In the main model (scenario 1), averages of the outcome data from the German and the US study were included to base the analysis on clinical findings from a variety of different MSU projects operating under different circumstances. Additional scenario 2 was created based on the reported outcomes from only the US trial (Supplementary Table 1) and differences in the reported rate of t-PA treatment, while other input parameters remained unchanged.

Model input parameters

Input parameters were derived from peer-reviewed literature (Supplementary Table 1) in accordance with international recommendations on the methodological framework of cost-effectiveness analyses.[19,26] No patient-level human data was analyzed for this study. Therefore, local IRB approval was not necessary. See also Supplementary Tables 1, 2, and 3.

Initial and transition probabilities

The average age was set to 70 years. For the base model, the proportion of patients presenting with strokes (ischemic and hemorrhagic strokes) versus stroke mimics as well as the rate of ischemic versus hemorrhagic strokes was derived from the MSU study of Grotta et al.[9] there was no data available from the German study. Plausibility was confirmed with the national stroke statistics of the American Heart Association.[27]

Grotta et al. reported a proportion of 85.0% (MSU) and 66.4% (conventional care) of patients to be t-PA eligible and to receive t-PA.[9] Ebinger et al. reported considerably lower rates of IVT of 60.3% (MSU) and 48.1% (EMS).[8] Stroke mimics were estimated to be judged t-PA eligible in 56.9% of MSU patients and in 47.5% of EMS patients in the model, based on the publication of Grotta et al.[9]

Both studies reported 90-day outcomes after initial stroke treatment as mRS scores, and average outcomes were included in the main model. The outcome of stroke mimic patients as well as hemorrhagic stroke patients was obtained from the study of Grotta et al.[9] The rate of interfacility transfers in the EMS group was estimated based on the US national inpatient sample for ischemic stroke as well as hemorrhagic stroke.[20,21]

Costs

The perspective of the US healthcare system was taken to calculate cumulative discounted costs in USD. All costs were adjusted to 2020 values using the medical component of the consumer price index.[28] Third-party hospital costs for acute stroke care as well as post-hospitalization costs depending on poststroke disability within the first 365 days were included from a nationwide cost analysis of acute stroke care costs by Mu et al.[29] along with the cost of IVT[30] and mechanical thrombectomy.[31] The costs of EMS transportation[32] were included for patients both in the MSU and conventional care group. Treatment costs for stroke mimics,[33] intracerebral hemorrhage,[34] and recurrent strokes[35] were estimated based on literature as well as long-term healthcare costs of stroke survivors which were estimated according to a previous long-term projection of a patient cohort of n = 428.[31] Varying levels of costs per dispatch of MSU have been assumed in the present study since there is no generally established patient-level cost estimate for MSU in the US costs of MSU were applied to hemorrhagic stroke patients and stroke mimics as well as ischemic stroke patients as these were considered to receive initial treatment by MSU.

Utilities

Outcomes were simulated in terms of QALYs which were obtained by multiplying the years spent within a specific health state by the utility levels. Conversion of mRS states to stroke-related utility weights was based on recent literature.[22]

Cost-effectiveness analysis

Treatment strategies were compared in terms of incremental costs, incremental effectiveness, and ICERs for varying MSU costs. The willingness-to-pay (WTP) thresholds were based on the WHO-CHOICE recommendations to consider 1x the country-specific gross domestic product (GDP) per capita as highly cost-effective and 3x the country-specific GDP per capita as cost-effective.[36] Resulting thresholds for the United States were USD 63,593 (highly cost-effective) and USD 190,779 (cost-effective) based on 2020 data from the World Bank.[37] All costs and outcomes were discounted by 3% annually, as recommended by Sanders et al.[26]

Sensitivity analysis

Deterministic and probabilistic sensitivity analyses were performed to analyze the impact of uncertainty, assuming average MSU costs of USD 10,000 as there is no established patient-level MSU cost.

Deterministic sensitivity analysis was conducted to reveal possible instability of the model depending on single input parameters. The rate of stroke mimics, percentage of patients being t-PA-eligible and the chance of receiving t-PA would possibly be influenced by the criteria for MSU dispatch. Hence, these factors were tested within wide plausible ranges.

Probabilistic sensitivity analysis was used to simultaneously vary multiple input parameters in a random manner based on their probability distributions reported in Supplementary Table 1. The model outcomes were computed for 30,000 Monte Carlo simulations.

Results

In the base case scenario (scenario 1), conventional care resulted in average discounted outcomes of 5.295 QALYs per patient over a lifetime horizon, whereas dispatch of MSU resulted in 5.886 QALYs. Assuming varying costs per dispatch of MSU, the resulting discounted cumulative lifetime costs and ICER values are reported in Table 1. Simulations based on the US outcome data (scenario 2) resulted in 4.652/5.303 QALYs for conventional care/MSU. Results of modeling a short time horizon of 1 year and 5 years, and results of modeling outcomes exclusively of stroke patients are presented in Supplementary Tables 4 and 5. Survival rates and disability rates (mRS3-5) are reported in Supplementary Figure S4.

Below a MSU cost cut-off per patient of USD 5,469, cumulative average lifetime costs of the MSU group were smaller than of the conventional care group and MSU was cost-saving. The threshold for scenario 2 was USD 8946.

When the cost of MSU did not exceed USD 43,067 the resulting ICER remained below a WTP threshold of USD 63,593 per QALY gained. For scenario 2, this threshold was exceeded at costs of USD 50,361. The simulation of MSU cost thresholds is shown in Figure 2(a). The ICER of USD 190,779 was exceeded at costs of USD 118,263 in scenario 1 and costs of USD 133,192 in scenario 2, respectively.

Sensitivity analyses

For sensitivity analyses, MSU costs were set to USD 10,000, resulting in average discounted lifetime costs per

Table 1. Results for different simulated mobile stroke unit (MSU) costs.

Strategy		Cost (USD)	Incremental cost (USD)	Effectiveness (QALYs)	Incremental effectiveness (QALYs)	ICER (USD per QALY)
				Scenario 1/ scenario 2 (US)		
Conventional care by EMS		285,872/ 328,063	-	5.295/ 4.652	-	-
Additional MSU at costs of	USD 10,000	290,403/ 329,117	4531/ 1054	5.886/ 5.303	0.591/ 0.651	7664/ 1619
	USD 20,000	300,403/ 339,117	14,531/ 11,054	5.886/ 5.303	0.591/ 0.651	24,578/ 16,974
	USD 30,000	310,403/ 349,117	24,531/ 21,054	5.886/ 5.303	0.591/ 0.651	41,492/ 32,328
	USD 40,000	320,403/ 359,117	34,531/ 31,054	5.886/ 5.303	0.591/ 0.651	58,406/ 47,683
	USD 50,000	330,403/ 369,117	44,531/ 41,054	5.886/ 5.303	0.591/ 0.651	75,319/ 63,038

ICER: incremental cost-effectiveness ratio; MSU: mobile stroke unit; USD: US dollars; QALYs: QALYs: quality-adjusted life years.

patient of USD 290,403 and an ICER of USD 7664 per QALY gained. Increasing the costs of MSU results in higher cumulative costs for MSU patients and impaired cost-effectiveness (Figure 2).

The cost-effectiveness of MSU was highly sensitive to changes in the proportion of patients with stroke mimics, with more mimics leading to increased costs without associated gains in QALYs (Figure 2(b)). A stroke mimic rate of 30% would result in an increased ICER of USD 13,201 per QALY gained. Small one-time costs, such as interfacility transfers, had minor influence on lifetime cost-effectiveness (Supplementary Figure S2a).

Variations of long-term costs due to stroke disability had a significant impact on the resulting cost-effectiveness (Supplementary Figure S2(a)), with long-term costs of mRS 0 and mRS 5 as the most influential determinants. When varying the utility weights by $+-0.1$, the strongest impact on the model outputs was observed for mRS 0. When utility weights of patients with mRS scores of 0 were decreased from 1.0 to 0.9, the resulting ICER increased to USD 8,558 per QALY (Supplementary Figure S2(b)). The impact of varying discount rates on the ICER is shown in Supplementary Figure S2(b).

In probabilistic sensitivity analysis, at a WTP threshold of USD 63,593 per QALY, and a cost of MSU of USD 10,000, MSU was cost-effective in almost 100% of iterations (Figure 3(a) and (b)).

Discussion

This economic evaluation of MSU is based on the best available evidence from the most recent prospective trials and reconfirms the hypothesis that MSU could be highly cost-effective in acute stroke care, even when assuming a wide range of plausible costs per patient for MSU.

This study has several distinctive features. To the authors' knowledge, this is the first cost-effectiveness model based on clinical outcomes achieved in both the United States. and German-controlled studies, including data from 2500 stroke patients in a total of 8 sites in recent prospective controlled trials, therefore representing a broad range of real-world clinical outcomes of MSU operation achieved within different program and staffing design settings, population densities, alarming distances, medical care infrastructure, and dispatchment rules in recent years.

This model incorporates a lifetime perspective on economic implications of MSU utilization, not only a short perspective of 3 months or 1 year. The strengths of the model presented here are the combination of short-term aspects together with a long-term modeling approach which has been previously applied to other stroke-related analyses.[38,39] The short-term perspective does not only include ischemic stroke patients but also simulates costs of patients with hemorrhagic strokes and stroke mimics therefore reducing potential bias. It integrates the economic effects of reduced interfacility transfers by MSU, thus adopting the perspective of a real-world management of suspected stroke patients. The modeling of separate scenarios facilitates an in-depth understanding of MSU operation based on a spectrum of possible outcomes within different structural and regulatory boundaries.

As there is no established MSU cost threshold at the moment, reported annual program costs vary substantially depending on healthcare systems, providers, equipment and personnel employed, ranging from USD 500,000 to USD 2,000,000.[11,17,40] Costs are mainly caused by hardware and

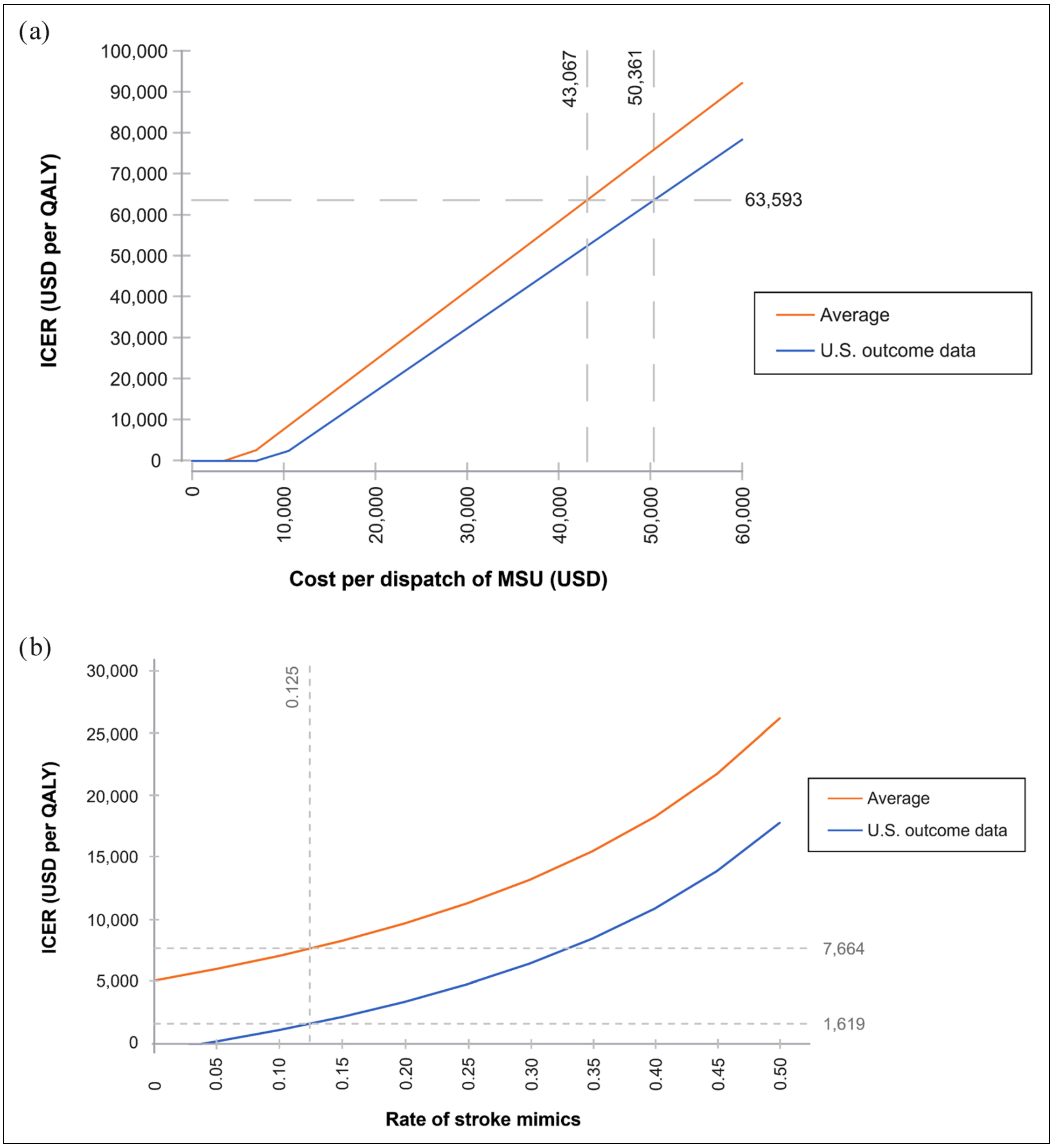

Figure 2 (a and b). Impact of cost per dispatch of mobile stroke unit (MSU) and rate of stroke mimics on incremental cost-effectiveness ratio (ICER) of MSU. Simulations were conducted based on the US outcome data and average of the US and German outcomes in order to demonstrate a range of plausible outcomes. (a) Variations of the assumed cost per dispatch of MSU and resulting cost-effectiveness. Simulating cost-effectiveness for the US outcome data resulted in lower ICERs compared to averages. (b) Variations of the rate of stroke mimics and the resulting cost-effectiveness. In the base case scenario, a rate of stroke mimics of 12.5% was assumed based on Grotta et al.[9] Assuming higher rates of stroke mimics resulted in impaired cost-effectiveness of MSU.

staffing,[10,11] which may be made more efficient by telemedicine equipment[41] depending on local regulations.[10,15] Potential numbers of patients are limited by coverage areas,[40,41] however, innovative approaches such as rendezvous strategies in which EMS and MSU teams meet halfway promise substantial expansion of coverage.[42,43]

The economic model outcomes can be considered valid particularly for MSU programs operating in similar urban set-ups as the inputs are based on real-world data. Sensitivity analysis confirmed that in the short-term perspective, a higher rate of stroke mimic patients adds to the costs without substantially improving outcomes. This underlines the importance of early identification of mimic patients, ideally at the level of dispatch. Rates of stroke mimics are reported in a range up to 27.6%[44] and may be even higher in a real-world setting depending on, for example, local alarming criteria. However, the estimate of 13.3% (MSU) and 11.4% (EMS) as reported by Grotta et al.[9] represents the

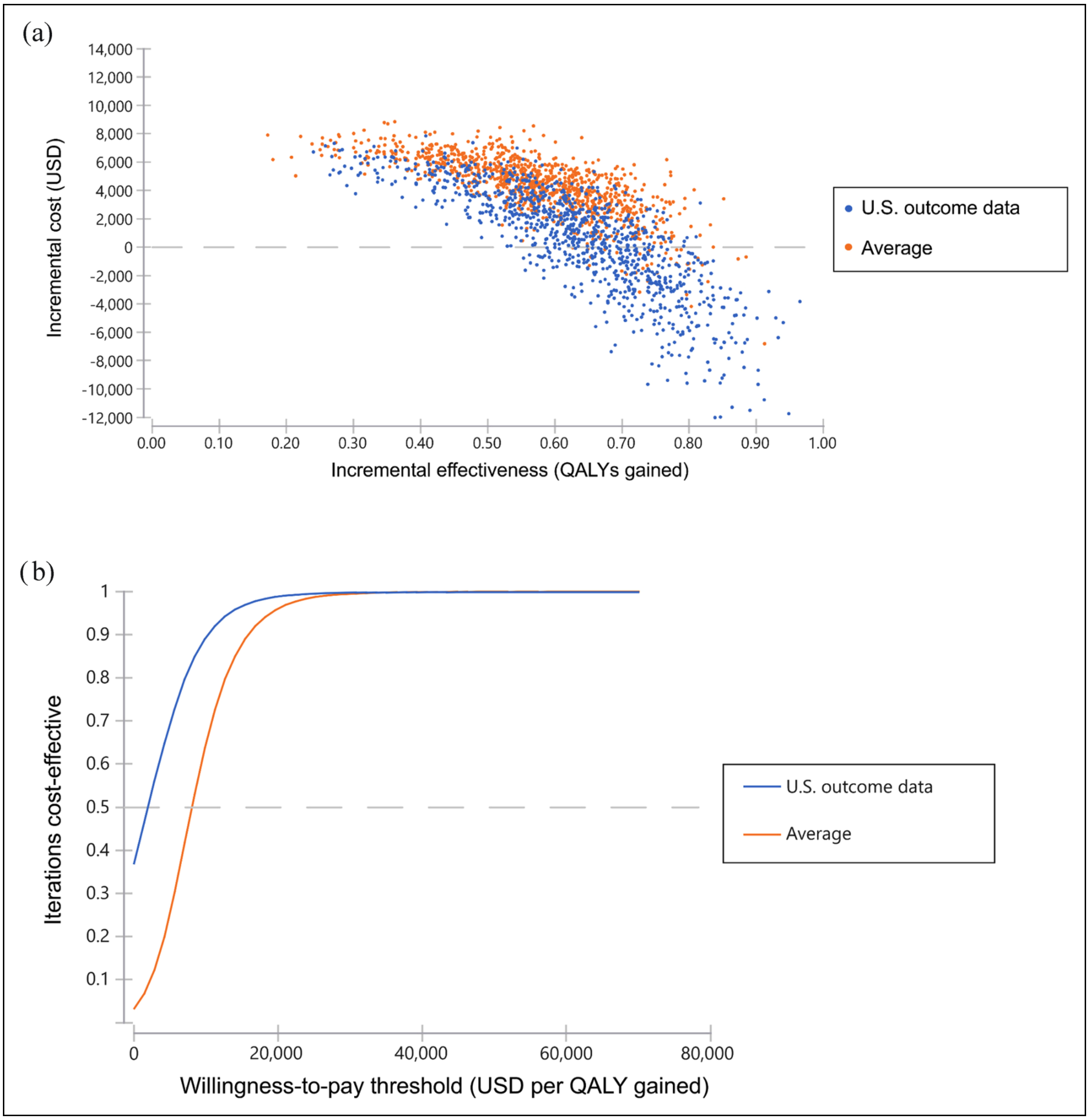

Figure 3 (a and b). Probabilistic sensitivity analysis and Monte Carlo simulation with 30,000 iterations for the base case scenario. (a) Results of 1000 simulations of incremental costs and incremental outcomes of mobile stroke unit (MSU) versus conventional care at a cost of US dollars (USD) 10,000 per dispatch. (b) Cost-effectiveness acceptability curve for varying willingness-to-pay (WIP) thresholds demonstrates that the majority of iterations are cost-effective even at conservative thresholds.

most recent prospectively acquired data and was hence applied in this study. Cost-effectiveness was very sensitive to changes in short-term poststroke costs, indicating that substantial positive economic returns can be expected even in a short-term horizon. Considering the long-term perspective, the model is even more sensitive to poststroke disability-related healthcare costs especially for patients with mRS 0 and 5, which demonstrates that the economic rationale for MSU utilization is depending on its potential to reduce disability-related, long-term downstream costs.

The model's sensitivity to the assigned utility levels was comparably smaller; however, the different utilities assigned to mRS states especially at the high and low end were shown to influence cost-effectiveness. Accurate conversion of mRS states to utility levels and QALYs therefore is crucial to obtain valid model outcomes. Multiple methods of mRS conversion have been described,[45] the data used for this study were applied by the majority of prior economic evaluations. Further real-world data on stroke-related quality of life would enable more accurate modeling of QALYs in future MSU evaluations.

Interestingly, the rate of averted secondary transfers did only have a very narrow effect on cost-effectiveness due to its relatively small one-time costs.

This economic evaluation adds a new perspective as it does not assume a single baseline estimate of MSU costs but it simulates varying costs per dispatch and identifies patient-level cost thresholds to maintain cost-effectiveness. Based on the resulting cost thresholds, program managers can create economically sustainable programs in adjusting coverage area sizes, coverage hours and staffing and hardware investments.

In order to develop a broader understanding of cost-effectiveness, further studies on implications of MSU deployment strategies as well as geographical and clinical characteristics on program effectiveness and healthcare costs are needed. For example, reduction of time to mechanical thrombectomy has been shown to be associated with higher poststroke QALYs.[18,39,46] This promising effect was not observed in the two underlying trials and therefore not separately modeled in this analysis, however, as some sites independently reported successful shortening of time to mechanical thrombectomy, there is potential for further improvement of outcomes.[18,47–49]

The findings of this study have to be interpreted in the light of several limitations. The economic model represents simplified diagnostic and therapeutic pathways and is limited by the quality and validity of its input variables. The enrollment strategies of the two MSU trials did not include all patients that were treated by MSU. Patient group imbalances, the non-randomized designs, study drop-outs, and partly retrospective evaluations may limit the validity of model inputs. Heterogeneity of the study populations like baseline age difference, stroke severity difference, and different exclusion criteria for subgroups along with dilution effects caused by MSU cancellations may impair comparability of the scenarios. Treatment outcomes for patients with hemorrhagic strokes and stroke mimics patients were derived from the BEST-MSU study and simulated for 1 year, which might underestimate the potential of an accurate on-site diagnosis by MSU in these patients as various new treatment approaches are being evaluated at the moment,[50] underlining the need for future model improvement. Precise patient-level simulations of cost-effectiveness and even patient subgroup analyses can be achieved with a complete body of data collected for a longer period of time after a stroke event and therefore are expected to be available from the investigators of the source trials in the future.

Evidence on long-term healthcare costs of stroke survivors is scarce and most cost-effectiveness analyses rely on the same, limited cost data. The 1-year unit costs for stroke management were derived from a study analyzing a nationwide cohort of more than 200,000 patients from between 2006 and 2015, whereas longer-term costs were sourced from another trial analyzing a cohort of 429 patients from Illinois, Texas, and Florida. Since the clinical outcomes were achieved within urban settings at daytime, the results may not be transferable to different circumstances. Clinical effectiveness of MSU in different surroundings like rural areas, large catchment zones, or cities in other continents should be considered an important focus for further research.

Conclusion

In conclusion, the findings of this study reconfirm the economic value of telemedicine-enabled MSU for prehospital stroke treatment. The resulting cost thresholds suggest favorable cost-effectiveness across a wide range of possible MSU program configurations as long as MSU creates substantial and reliable reduction of long-term disability and associated costs. Close attention should be paid to optimizing patient selection as the proportion of stroke mimics patients represents a key determinant of cost-effectiveness.

Declaration of conflicting interests

The authors declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: JSR, MFF, SOS, and FT: The Department of Radiology and Nuclear Medicine has research agreements with Siemens Healthineers. KS, CH, MN, and KCF: The authors declare that there is no conflict of interest.

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Availability of data materials

The detailed input data and general model structure of this economic evaluation are available from the corresponding author upon reasonable request

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Supplemental material

Supplemental material for this article is available online.

References

1. GBD 2016 Stroke Collaborators. Global, regional, and national burden of stroke, 1990–2016: A systematic analysis for the global burden of disease study 2016. *Lancet Neurol* 2019; 18: 439–458.
2. Demaerschalk BM, Hwang H-M and Leung G. US Cost burden of ischemic stroke: A systematic literature review. *Am J Manag Care* 2010; 16: 525–533.
3. Saver JL, Goyal M, van der Lugt A, et al. Time to treatment with endovascular thrombectomy and outcomes from ischemic stroke: A meta-analysis. *JAMA* 2016; 316: 1279–1289.
4. Potla N and Ganti L. Tenecteplase vs. alteplase for acute ischemic stroke: a systematic review. *Int J Emerg Med* 2022; 15(1): 1.

5. Kim J-T, Fonarow GC, Smith EE, et al. Treatment with tissue plasminogen activator in the golden hour and the shape of the 4.5-hour time-benefit curve in the national United States get with the guidelines-stroke population. *Circulation* 2017; 135: 128–139.
6. Fassbender K, Walter S, Liu Y, et al. 'Mobile stroke unit' for hyperacute stroke treatment. *Stroke* 2003; 34: e44.
7. Walter S, Kostopoulos P, Haass A, 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.
8. Ebinger M, Siegerink B, Kunz A, 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.
9. Grotta JC, Yamal J-M, Parker SA, et al. Prospective, multicenter, controlled trial of Mobile Stroke Units. *N Engl J Med* 2021; 385: 971–981.
10. Fassbender K, Merzou F, Lesmeister M, et al. Impact of mobile stroke units. *J Neurol Neurosurg Psychiatry* 2021; 92(8): 815–822.
11. Bowry R and Grotta JC. Mobile Stroke Units: Current and future impact on stroke care. *Semin Neurol* 2021; 41: 9–15.
12. Scuffham PA and Tippett V. The cost-effectiveness of thrombolysis administered by paramedics. *Curr Med Res Opin* 2008; 24: 2045–2058.
13. Walter S, Grunwald IQ, Helwig SA, et al. Mobile Stroke Units - cost-effective or just an expensive hype? *Curr Atheroscler Rep* 2018; 20: 49.
14. Southerland AM and Brandler ES. The cost-efficiency of mobile stroke units: Where the rubber meets the road. *Neurology* 2017; 88: 1300–1301.
15. Dietrich M, Walter S, Ragoschke-Schumm A, et al. Is prehospital treatment of acute stroke too expensive? An economic evaluation based on the first trial. *Cerebrovasc Dis* 2014; 38: 457–463.
16. Gyrd-Hansen D, Olsen KR, Bollweg K, et al. Cost-effectiveness estimate of prehospital thrombolysis: Results of the PHANTOM-S study. *Neurology* 2015; 84: 1090–1097.
17. Reimer AP, Zafar A, Hustey FM, et al. Cost-Consequence analysis of Mobile Stroke Units vs. Standard prehospital care and transport. *Front Neurol* 2019; 10: 1422.
18. Kim J, Easton D, Zhao H, et al. Economic evaluation of the Melbourne Mobile Stroke Unit. *Int J Stroke* 2021; 16: 466–475.
19. Husereau D, Drummond M, Augustovski F, et al. Consolidated health economic evaluation reporting standards 2022 (CHEERS 2022) statement: Updated reporting guidance for health economic evaluations. *Value Health* 2022; 25: 3–9.
20. George BP, Pieters TA, Zammit CG, et al. Trends in interhospital transfers and mechanical thrombectomy for United States acute ischemic stroke inpatients. *J Stroke Cerebrovasc Dis* 2019; 28: 980–987.
21. Bako AT, Bambhroliya A, Meeks J, et al. National trends in transfer of patients with primary intracerebral hemorrhage: An analysis of 12-year nationwide data. *J Stroke Cerebrovasc Dis* 2021; 30: 106116.
22. Chaisinanunkul N, Adeoye O, Lewis RJ, et al. Adopting a patient-centered approach to primary outcome analysis of acute stroke trials using a utility-weighted modified rankin scale. *Stroke* 2015; 46: 2238–2243.
23. Arias E, Heron M and Xu J. United States life tables, 2014. *Natl Vital Stat Rep* 2017; 66: 1–64.
24. Hong K-S and Saver JL. Years of disability-adjusted life gained as a result of thrombolytic therapy for acute ischemic stroke. *Stroke* 2010; 41: 471–477.
25. Pennlert J, Eriksson M, Carlberg B, et al. Long-term risk and predictors of recurrent stroke beyond the acute phase. *Stroke* 2014; 45: 1839–1841.
26. Sanders GD, Neumann PJ, Basu A, et al. Recommendations for conduct, methodological practices, and reporting of cost-effectiveness analyses: Second panel on cost-effectiveness in health and medicine. *JAMA* 2016; 316: 1093–1103.
27. Virani SS, Alonso A, Benjamin EJ, et al. Heart disease and stroke statistics-2020 update: A report from the American heart association. *Circulation* 2020; 141(9): e139–e596.
28. How BLS Measures Price Change for Medical Care Services in the Consumer Price Index : U.S. Bureau of Labor Statistics, https://www.bls.gov/cpi/factsheets/medical-care.htm (2020, accessed on 16 October 2021).
29. Mu F, Hurley D, Betts KA, et al. Real-world costs of ischemic stroke by discharge status. *Curr Med Res Opin* 2017; 33: 371–378.
30. Kazley AS, Simpson KN, Simpson A, et al. Optimizing the economic impact of rtPA use in a stroke belt state: The case of South Carolina. *Am Health Drug Benefits* 2013; 6: 155–163.
31. Shireman TI, Wang K, Saver JL, et al. Cost-Effectiveness of solitaire stent retriever thrombectomy for acute ischemic stroke: Results from the SWIFT-PRIME trial (Solitaire with the intention for thrombectomy as primary endovascular treatment for acute ischemic stroke). *Stroke* 2017; 48: 379–387.
32. 2021 Ambulance Fee Schedule, https://hcpcs.codes/fee-schedule/ambulance (2021, accessed on 12 October 2021).
33. Scott KW, Liu A, Chen C, et al. Healthcare spending in U.S. Emergency departments by health condition, 2006–2016. *PLoS One* 2021; 16: e0258182.
34. Nguyen C, Mir O, Vahidy F, et al. Resource utilization for patients with intracerebral hemorrhage transferred to a comprehensive stroke center. *J Stroke Cerebrovasc Dis* 2015; 24: 2866–2874.
35. Chambers MG, Koch P and Hutton J. Development of a decision-analytic model of stroke care in the United States and Europe. *Value Health* 2002; 5: 82–97.
36. McDougall JA, Furnback WE, Wang BCM, et al. Understanding the global measurement of willingness to pay in health. *J Mark Access Health Policy* 2020; 8(1): 1717030.
37. GDP per capita (current US$) - United States Data, https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=US (2020, accessed on 20 February 2022).
38. Gao L, Moodie M, Mitchell PJ, et al. Cost-Effectiveness of tenecteplase before thrombectomy for ischemic stroke. *Stroke* 2020; 51: 3681–3689.
39. Kunz WG, Almekhlafi MA, Menon BK, et al. Public health and cost benefits of successful reperfusion after thrombectomy for stroke. *Stroke* 2020; 51: 899–907.
40. Calderon VJ, Kasturiarachi BM, Lin E, et al. Review of the Mobile Stroke Unit experience worldwide. *Interv Neurol* 2018; 7: 347–358.
41. Harris J. A review of mobile stroke units. *J Neurol* 2021; 268: 3180–3184.

42. Mathur S, Walter S, Grunwald IQ, et al. Improving prehospital stroke services in rural and underserved settings with Mobile Stroke Units. *Front Neurol* 2019; 10: 159.
43. Shuaib A and Jeerakathil T. Alberta Mobile Stroke Unit investigators. The mobile stroke unit and management of acute stroke in rural settings. *CMAJ* 2018; 190: E855–E858.
44. Grunwald IQ, Phillips DJ, Sexby D, et al. Mobile Stroke Unit in the UK healthcare system: Avoidance of unnecessary accident and emergency admissions. *CED* 2020; 49: 388–395.
45. Wu X, Khunte M, Gandhi D, et al. A systematic review of cost-effectiveness analyses on endovascular thrombectomy in ischemic stroke patients. *Eur Radiol* 2022; 32: 3757–3766.
46. van Voorst H, Kunz WG, van den Berg LA, et al. Quantified health and cost effects of faster endovascular treatment for large vessel ischemic stroke patients in the Netherlands. *J Neurointerv Surg* 2021; 13: 1099–1105.
47. Bender MT, Mattingly TK, Rahmani R, et al. Mobile stroke care expedites intravenous thrombolysis and endovascular thrombectomy. *Stroke Vasc Neurol* 2021; 7(3): 209–214.
48. Czap AL, Singh N, Bowry R, et al. Mobile Stroke Unit computed tomography angiography substantially shortens door-to-puncture time. *Stroke* 2020; 51: 1613–1615.
49. Cerejo R, John S, Buletko AB, et al. A Mobile Stroke treatment unit for field triage of patients for intraarterial revascularization therapy. *J Neuroimaging* 2015; 25: 940–945.
50. Hariharan P, Tariq MB, Grotta JC, et al. Mobile stroke units: Current evidence and impact. *Curr Neurol Neurosci Rep* 2022; 22(1): 71–81. DOI: 10.1007/s11910-022-01170-1.