

Is Prehospital Treatment of Acute Stroke too Expensive? An Economic Evaluation Based on the First Trial

Martin Dietrich^a Silke Walter^b Andreas Ragoschke-Schumm^a Stefan Helwig^b
Steven Levine^c Clotilde Balucani^c Martin Lesmeister^b Anton Haass^b
Yang Liu^b Hans-Morten Lossius^d Klaus Fassbender^b

^aChair of Business Administration and Health Services Management Research, Saarbrücken, and ^bDepartment of Neurology, Saarland University, Homburg, Germany; ^cDepartment of Neurology and Stroke Center, SUNY College of Medicine and Downstate Medical Center, Brooklyn, N.Y., and Kings County Hospital Center, Brooklyn, N.Y., USA; ^dResearch and Development, The Norwegian Air Ambulance Foundation, Oslo, Norway

Key Words

Acute stroke · Prehospital stroke treatment · Benefit-cost ratio · Cost effectiveness · Mobile stroke unit

Abstract

Background: Recently, a strategy for treating stroke directly at the emergency site was developed. It was based on the use of an ambulance equipped with a scanner, a point-of-care laboratory, and telemedicine capabilities (Mobile Stroke Unit). Despite demonstrating a marked reduction in the delay to thrombolysis, this strategy is criticized because of potentially unacceptable costs. **Methods:** We related the incremental direct costs of prehospital stroke treatment based on data of the first trial on this concept to one year direct cost savings taken from published research results. Key parameters were configuration of emergency medical service personnel, operating distance, and population density. Model parameters were varied to cover 5 different relevant emergency medical service scenarios. Additionally, the effects of operating distance and population density on benefit-cost ratios were analyzed. **Results:** Benefits of the concept of pre-

hospital stroke treatment outweighed its costs with a benefit-cost ratio of 1.96 in the baseline experimental setting. The benefit-cost ratio markedly increased with the reduction of the staff and with higher population density. Maximum benefit-cost ratios between 2.16 and 6.85 were identified at optimum operating distances in a range between 43.01 and 64.88 km (26.88 and 40.55 miles). Our model implies that in different scenarios the Mobile Stroke Unit strategy is cost-efficient starting from an operating distance of 15.98 km (9.99 miles) or from a population density of 79 inhabitants per km² (202 inhabitants per square mile). **Conclusion:** This study indicates that based on a one-year benefit-cost analysis that prehospital treatment of acute stroke is highly cost-effective across a wide range of possible scenarios. It is the highest when the staff size of the Mobile Stroke Unit can be reduced, for example, by the use of telemedical support from hospital experts. Although efficiency is positively related to population density, benefit-cost ratios can be greater than 1 even in rural settings.

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M.D. and S.W. contributed equally to this work.

Introduction

Stroke is the most frequent cause of permanent disability among adults and one of the most frequent causes of death [1]. In addition to the considerable suffering involved in the life of the individual, stroke results in enormous societal costs associated with long-term care, rehabilitation, and loss of workforce members [2, 3].

Today, acute ischemic stroke is treatable by thrombolysis with recombinant tissue-type plasminogen activator (rt-PA), as evidenced by large controlled studies [4, 5], and economic evaluations indicate its cost-effectiveness [6–8]. However, across the entire population of stroke patients, rt-PA treatment is administered only to 2–7% of patients [9, 10]. One main reason for the detrimental underuse of rt-PA is that most patients arrive at the hospital too late to be considered for thrombolysis. Previous studies found that only 19–60% of stroke patients arrive at the hospital within 3 h, and only 14–32% arrive within 2 h [9, 11, 12]. Disappointingly, data from the Get With The Guidelines-Stroke program show that the proportion of stroke patients arriving early did not increase from 2003 to 2009, despite serious efforts [10] taken in this regard.

Recently, the concept of providing treatment directly at the emergency site has been shown to be feasible and to significantly reduce the delay to treatment [13, 14]. The concept is based on the use of an otherwise normally equipped ambulance (Mobile Stroke Unit; MSU) that, additionally, includes a computed tomography (CT) scanner, a point-of-care laboratory system, and a telemedicine connection to the hospital [15, 16].

A first prospective randomized trial demonstrated a 50% reduction in the delay to a therapy decision [17]. In this trial, 57% of patients in the intervention group but only 4% of those in the control group received a therapy decision within 60 min after symptom onset (which is referred to as the ‘golden hour’). These findings contrast markedly with the door-to-needle times of 60 min recommended by current stroke guidelines [18, 19] or the much longer delays seen in clinical reality [20, 21].

Although there is – according to the generally accepted ‘time-is-brain concept’ [22] – less controversy about the assumption that earlier stroke treatment is associated with a better outcome, important concerns exist with regard to the potentially unacceptable cost of prehospital stroke treatment. In this study we analyzed the benefit-cost ratio of this novel strategy in a wide range of possible scenarios.

Methods

Type of Evaluation

We calculated benefit-cost ratios as direct cost savings in relation to incremental total direct costs associated with prehospital stroke treatment on a one-year basis. Incremental total direct costs were calculated by a deterministic cost model that was parameterized by the results of the first trial on prehospital thrombolysis [17]. Monetary benefits were derived from improved outcomes due to additional thrombolysis within 180 min enabled by the MSU strategy and based on direct avoided costs during the first year after stroke [23, 24].

Assumptions of Direct Costs of the Experimental MSU

In the setting of the first trial [17], the experimental MSU operated in addition to the normal emergency medical service (EMS) (Scenario 1). The EMS, specifically in the Saarland, Germany, consists of an ambulance staffed by one paramedic and one emergency assistant and another ambulance staffed with one physician and one paramedic (‘physician-based’ EMS system) [16]. This specific setting was used as a control setting in order to parameterize the cost model and to calculate benefit-cost ratios for the original study setting (Scenario 1; table 1). The population density was 344 persons per km² (880 persons per square mile), and the stroke incidence rate was 400 per 100,000 persons per year. Eighty percent of all strokes were assumed to be ischemic. The thrombolysis rate was assumed to be 32%, reflecting the rate in the conservative treatment arm of the MSU trial (vs. 41% in the intervention arm) [17]. Based on a population size of 361,629 persons, the estimate of stroke incidence was 1,447, of which 371 were assumed to be ischemic strokes eligible for thrombolysis.

Initial parameters for time-to-treatment estimates were an operating distance of 30 km (18.75 miles), an average speed of 60 km/h (37.5 mph) for the unit, onsite treatment times of 30 min, setup time for MSU personnel recruited from the hospital of 10 min, an average total operating duration of 1 h and EUR 0.30 travelling costs per km (USD 0.37 per mile).

Assumptions of Benefits of the Experimental MSU

In the first trial of this strategy [17] more patients had therapy decision within the early temporal window with the MSU strategy than with the control treatment (fig. 1). Thus, we found that 72% of the patients in the MSU group could have been treated within the first 90 min and additional 28% between 90 and 180 min. In contrast, only 38% in the control group could have been treated within the first 90 min, and an additional 51% between 90 and 180 min [17].

According to a recent meta-analysis, number-needed-to-treat (NNT) for a favorable outcome of thrombolysis was 4.5 when treated in the first 90 min and 9 when treated within 90–180 min [24]. Based on this data, we calculated that by using the MSU strategy, 59.4 of the 371 patients could have benefited by treatment within the first 90 min and additional 11.5 patients by treatment within 90–180 min. With conventional stroke management, 31.3 of the 371 patients could have benefited by treatment within 90 min and an additional number of 21 patients by treatment between 90 and 180 min. In summary, a total of 70.9 patients could have benefited in the MSU group, while only 52.3 patients may have benefited in the control group. Thus, 18.6 additional patients of the 371 ischemic stroke patients would have benefited from MSU treatment.

Table 1. Staffing, personnel costs per hour and cost differences of baseline scenario (Scenario 1) and alternative scenarios (2–5) compared to relevant control settings

| | Scenarios | | | | |
|---|-----------------|-----------------|----------------|---------------|---------------|
| | 1 | 2 | 3 | 4 | 5 |
| <i>Emergency unit</i> | | | | | |
| Emergency physician | 1 | 0 | 0 | 0 | 0 |
| Paramedic | 1 | 0 | 0 | 0 | 0 |
| <i>Ambulance unit</i> | | | | | |
| Paramedic | 1 | 1 | 0 | 0 | 0 |
| Emergency medical assistant | 1 | 1 | 0 | 0 | 0 |
| <i>MSU</i> | | | | | |
| Neurologist | 1 | 1 | 1 | 0 | 0 |
| Radiologist | 1 | 0 | 0 | 0 | 0 |
| Paramedic | 0 | 0 | 1 | 1 | 1 |
| Emergency medical assistant | 1 | 1 | 0 | 1 | 0 |
| Radiology technician | 0 | 1 | 1* | 1 | 1* |
| Personnel costs per hour (EUR (USD))** | 215.76 (265.09) | 135.87 (166.94) | 90.22 (110.85) | 75.00 (92.15) | 52.17 (64.10) |
| Personnel cost differences (EUR (USD))*** | 98.98 (121.61) | 87.01 (106.91) | 41.36 (50.82) | 26.14 (32.12) | 3.31 (4.07) |

* Radiology technician has additional emergency medical education. ** USD 1 = EUR 0.8139 (exchange rate December 6, 2014). *** Personnel cost differences were calculated in comparison to relevant control settings. Control setting in baseline scenario 1 were one emergency and one ambulance unit, personnel costs per hour = EUR 116.78 (USD 143.48); control setting in alternative scenarios 2–5 was one ambulance unit, personnel costs per hour = EUR 48.86 (USD 60.03).

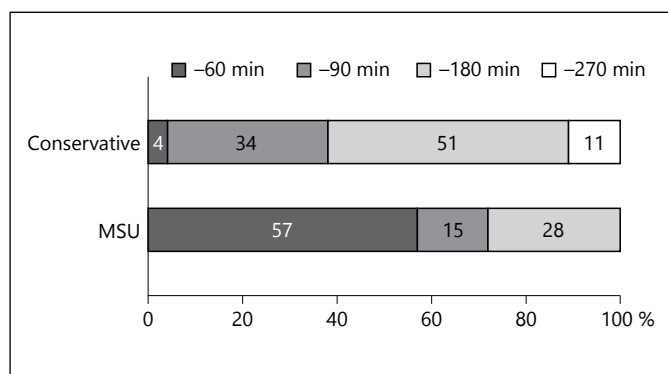


Fig. 1. Percentage of patients with different symptom onset-therapy decision times in the conservative stroke management group (n = 47) and MSU-based stroke management group (n = 53).

Direct costs in the first year after stroke, stratified for the level of functional outcomes (modified Rankin Scale; mRS), were taken from the study by Fjaertoft et al. [23]. Cost savings per year and numbers of treated patient were calculated as unweighted average difference between direct costs of mRS scores 0–1 and mRS scores 4–5 and between mRS scores 2–3 and mRS scores 4–5. This calculation resulted in an assumption of direct cost savings of EUR 17,872 (USD 21,958) per patient and year which were similar to other reported results [25]. Thus, the estimated direct total cost

savings during the first year after stroke associated with early thrombolysis were EUR 332,420 (USD 408,429).

The annual incremental direct costs of the MSU in this study were calculated as the costs of additional staffing and material in excess of the regular EMS (table 2). The annual total personnel expenses were EUR 77,000 (USD 94,606) for one emergency physician, EUR 70,000 (USD 86,006) for other physicians, EUR 48,000 (USD 58,975) for a paramedic, EUR 42,000 (USD 51,603) for an EMS assistant, and EUR 48,000 (USD 58,975) for a radiology technology assistant (cost information provided by the in-house accounting according to the current wage agreements of the German public service). Effective working hours were estimated at 1,840 h per person. In the baseline setting, the additional staffing costs of the MSU were EUR 98.98 (USD 121.61) per hour (table 1, Scenario 1). Based on an average duration of 1 h for each ambulance run, set-up time, and a hit rate (rate of actual strokes among all MSU dispatches) of 50%, the costs for the additional personnel required to staff the 741.2 MSU runs necessary for treating 371 patients with actual ischemic stroke would be EUR 82,761 (USD 101,684) per year.

The additional annual material costs of the MSU were EUR 87,042 (USD 106,944) and were composed of an annual linear depreciation of EUR 40,500 (USD 49,760), resulting from technology and hardware acquisition costs of EUR 405,000 (USD 497,604), operational costs of EUR 33,200 (USD 40,791) per year, and additional operation costs of the MSU of EUR 13,342 (USD 16,393) (table 2). Thus, the total additional direct costs consisting of personnel and material costs per year for operating the MSU are EUR 169,803 (USD 208,629).

Table 2. Baseline model parameters and cost assumptions

| Model parameters | Values |
|--|-------------------|
| Population density inhabitants per km ² (per square mile) | 344 (881) |
| Incidence per 100,000 (cases) | 400 |
| Thrombolysis rate, % | 32.0 |
| Hit rate, % | 50.0 |
| Max. street distance operational area, km (miles) | 30 (18.75) |
| Average speed, km/h (mph) | 60 (37.5) |
| Travelling cost per km (EUR (USD per mile)) | 0.30 (0.37) |
| Onsite duration, min | 30 |
| Setup-time MSU physicians, min | 10 |
| Direct costs: staffing and material costs p.a. (EUR (USD)) | |
| <i>Staffing*</i> | |
| Emergency physician | 77,000 (94,606) |
| Neurologist | 70,000 (86,006) |
| Radiologist | 70,000 (86,006) |
| Paramedic | 48,000 (58,975) |
| Emergency medical assistant | 42,000 (51,603) |
| Radiology technician | 48,000 (58,975) |
| <i>Material: MSU technology and hardware</i> | |
| CT original costs | 270,000 (331,736) |
| Laboratory equipment | 20,000 (24,573) |
| Telemedicine | 100,000 (122,865) |
| Conversion costs emergency vehicle | 15,000 (18,430) |
| Sum | 405,000 (497,604) |
| Depreciation p.a. (linear, 10 years) | 40,500 (49,760) |
| <i>Material: maintenance</i> | |
| CT maintenance | 30,000 (36,860) |
| Reagents | 1,200 (1,474) |
| Telecommunication SIM | 2,000 (2,457) |
| Sum | 33,200 (40,791) |
| Total material costs | 73,700 (90,552) |
| Direct monetary benefits: one year cost savings (EUR (USD)) | |
| Direct cost savings per patient** | 17,872 (21,958) |

* Staffing costs on a yearly basis were used to calculate costs per hour in the emergency settings, which varied in the staffing scenarios 1–5. ** Direct cost savings per patient were calculated based on Fjaertoft et al. [23] as unweighted averaged differences between direct costs of mRS 0–1 and mRS 4–5 and between mRS 2–3 and mRS 4–5.

CT = Computed tomography; MSU = mobile stroke unit; SIM = subscriber identity module.

Assumptions of Cost Savings in a Range of Other Possible EMS Scenarios (Scenarios 2–5)

The specific setting in the Saarland, Germany differs from other EMS settings, both nationally and internationally [16]. Therefore, we calculated the potential cost savings for other EMS scenarios (Scenarios 2–5; table 1). In order to adjust the calculations

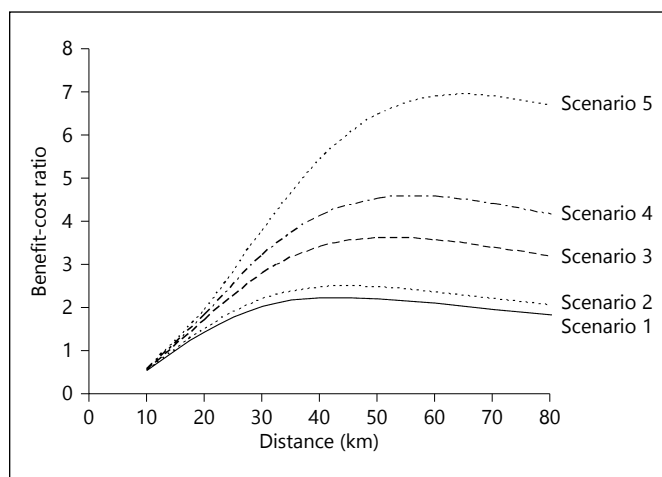


Fig. 2. Benefit-cost ratios with different staffing scenarios and average operating distances (Scenario 1: 3 physicians, 4 paramedics; Scenario 2: 1 physician, 1 technician, 3 paramedics; Scenario 3: 1 physician, 1 technician, 1 paramedic; Scenario 4: 1 technician, 2 paramedics; Scenario 5: 1 technician, 1 paramedic).

for international comparability, the control setting for calculating benefit-cost ratios in Scenarios 2–5 does not include the additional team consisting of the physician and a driver (paramedic) ('paramedic based EMS system'). Personnel costs with a moderate staff reduction (Scenario 2) resulted in incremental total costs of EUR 156,233 (USD 191,956). In the scenario with the maximum reduction of personnel (Scenario 5), in which the MSU would be staffed only with a paramedic and a radiology technician guided by hospital experts via telemedicine and replaced the regular paramedic based EMS, additional total direct costs were EUR 89,498 (USD 109,962) per year.

Effects of Operating Distances and Population Density

We estimated benefit-cost ratios for various operating distances ranging from 10 to 80 km (6.25 to 50 miles). These estimates resulted in different sizes of operating areas and populations. We also calculated benefit-cost ratios for population densities as high as 3,500 inhabitants per km² (8,960 inhabitants per square mile) so that we could calculate benefit-cost ratios in rural and urban regions.

Results

Benefit-Cost Ratios for Various Scenarios

With an average operating distance of 30 km (18.75 miles), the benefit-cost ratio for the baseline evaluation (Scenario 1) was 1.96 (EUR 332,420 (USD 408,429) divided by EUR 169,803 (USD 208,629)). At an operating distance of 30 km (18.75 miles) in Scenarios 2 through 5, the benefit-cost ratios further increased as the staff size was reduced, up to a benefit-cost ratio of 3.71 in Scenario 5 (fig. 2).

Effects of Operating Distances

Benefit-cost ratios depended on average operating distances in terms of street kilometers and related catchment areas (fig. 2). In Scenario 1, at an average driving distance of 10 km (6.25 miles), 40 km (25 miles), and 80 km (50 miles), the benefit-cost ratios were 0.46, 2.16, and 1.75, respectively. Cost-efficiency (benefit-cost ratio of 1) is reached at 15.98 km (9.99 miles), and the optimal operating distance for the maximal benefit-cost ratio of 2.16 was 43.01 km (26.88 miles). The optimal distances that maximize benefit-cost ratios vary according to the staffing scenarios, for a maximal ratio of 6.85 at 64.88 km (40.55 miles) in Scenario 5 (fig. 2).

Effects of Population Density

We analyzed various population densities up to 3,500 inhabitants per km² (8,960 inhabitants per square mile). At an operating distance of 30 km (18.75 miles), the benefit-cost ratios increased with population density for all staffing scenarios. In Scenario 1, at a higher population density of 3,500 inhabitants per km² (8,960 inhabitants per square mile) the model indicates a benefit-cost ratio of 3.22 and a benefit-cost ratio of 1 is reached at a population density of 107 inhabitants per km² (274 inhabitants per square mile). Results, therefore, indicate that MSU cost-efficiency is reached also in rural regions. When reducing staffing to the potential minimum as represented by Scenario 5, the benefit-cost ratio would increase to 16.13 at a population density of 3,500 inhabitants per km² (8,960 inhabitants per square mile), and cost-efficiency would be reached starting from a population density of 79 inhabitants per km² (202 inhabitants per square mile).

Discussion

Prehospital stroke treatment may be a solution for the serious medical problem of delivering existing treatment only to a minority of stroke patients; however, the cost of this strategy may be unacceptable for implementation as a clinical routine. The results of this economic evaluation, however, indicate that at the initial operating distance of 30 km (18.75 miles) and given the population density of 344 inhabitants per km² (881 inhabitants per square mile), the benefit of prehospital stroke treatment outweighs the cost with a benefit-cost ratio of 1.96. In different staffing scenarios and operating distances, benefit-cost ratios reached 6.85 and ratios further improved with higher population density.

Comparison with Previous Studies

Our systematic literature review did not yield any previous deterministic decision-analytic modeling studies specifically comparing prehospital stroke treatment with conventional treatment. However, earlier studies showed that various strategies that can decrease delay and increase thrombolysis rates (e.g., public education, prenotification, or in-hospital reconfigurations) resulted in relevant cost savings [26–29]. Thus, the findings of our study are in agreement with those of such previous studies.

The staff of the prototype ambulance consisted of a physician, a neuroradiologist, and a paramedic [17]; this ambulance was dispatched in addition to the routine EMS ambulance (which, in the Saarland, Germany, is staffed by 2 paramedics, an emergency physician, and a driver; ‘physician-based EMS configuration’) [16]. However, in other EMS settings, the ambulance staff might be gradually reduced to the minimal number necessary for high-quality stroke care (i.e., 2 stroke-trained paramedics, one trained to run a CT scanner, with guidance from hospital experts by telemedicine).

In this context, telestroke (real-time videoconferencing and transmission of videos between ambulance and hospital) [30] and teleneuroradiology (e.g., transmission of CT scans between ambulance and hospital) has, after initial problems, recently made important progress by implementing 4G connectivity and EMS prioritization.

A relevant determinant of cost is the utilization rate of the ambulance; this rate depends on the operating distance and population density. Benefit-cost ratios increased with the size of the operating area; optimal distances ranged from 43.01 to 64.88 km (26.88 to 40.55 miles), depending on the staffing scenarios.

Moreover, cost-efficiency increases with population density and appears, at first glance, to be especially advantageous in urban regions. However, the cost-efficiency of an MSU has already been reached in rural regions. Because these regions are often underserved with regard to stroke expertise, the medical value of this strategy may be especially high in rural areas.

Finally, an important factor for cost-efficiency is the hardware. Based on the use of standard ambulance solutions, cost incurred for the current ambulance was EUR 405,000 (USD 497,604) [31]. In the future, utilization rates could be improved if the EMS personnel used standardized scales for recognizing stroke symptoms [16]. Thus, in the baseline evaluation, reducing the stroke mimic rate from 50% to 40% would increase the incremental benefit-cost ratio from 1.96 to 2.16.

Limitations

We made specific assumptions with regard to input parameters specific to the first trial of this strategy. Other settings might require different specifications of incidence rates, population density, personnel costs, traffic, or legal frameworks. Moreover, we assessed cost savings only for the first year. Integration of long-term costs might result in higher benefit-cost ratios because of the chronic disability associated with stroke. Furthermore, we did not account for other potential beneficial effects such as earlier management of hemorrhage or more accurate triage decisions regarding the target hospital [13, 32].

Additionally, the cost model is a deterministic model that did not explicitly consider uncertainty. Empirical distributions of relevant input parameters were not available so that parameter values and results are to be inter-

preted as expectancy values. Additionally, we assumed that a single MSU is sufficient in all scenario settings so that an acquisition of an additional MSU due to high utilization was not considered. Nevertheless, the model can be used to run simulations with evidenced statistical distribution functions of relevant input parameters when available. Also our data analysis was based on the temporal distribution of the patients in the MSU trial, which were all treated within 3 h; therefore, additional effects of thrombolysis within 4.5 h could not be considered. Thus, the results of our model provide conservative estimates of benefit-cost ratios.

In conclusion, this analysis showed that the strategy of prehospital stroke treatment can be cost-efficient in a wide range of scenarios, with maximum benefit-cost ratios when we take advantage of the current technical progress in telemedicine.

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