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Cost-Effectiveness of Helicopter Versus Ground Emergency Medical Services for Trauma Scene Transport in the United States

M. Kit Delgado, MD, MS[1,2,4], **Kristan L. Staudenmayer, MD, MS**[3,4], **N. Ewen Wang, MD**[1,2,4], **David A. Spain, MD**[3,4], **Sharada Weir, PhD**[5], **Douglas K. Owens, MD, MS**[6,2], and **Jeremy D. Goldhaber-Fiebert, PhD**[2]

Kristan L. Staudenmayer: kristans@stanford.edu; N. Ewen Wang: ewen@stanford.edu; David A. Spain: dspain@stanford.edu; Sharada Weir: sharada.weir@umassmed.edu; Douglas K. Owens: owens@stanford.edu; Jeremy D. Goldhaber-Fiebert: jeremygf@stanford.edu

[1]Department of Surgery, Division of Emergency Medicine, Stanford University School of Medicine

[2]Center for Health Policy and Center for Primary Care and Outcomes Research, Stanford University School of Medicine

[3]Department of Surgery, Division of General Surgery, Trauma/Critical Care Section, Stanford University School of Medicine

[4]Stanford Investigators for Surgery, Trauma, and Emergency Medicine (SISTEM), Stanford University School of Medicine

[5]University of Massachusetts School of Medicine, Center for Health Policy and Research, Stanford University School of Medicine

[6]VA Palo Alto Health Care System, Palo Alto CA, Stanford University School of Medicine

Abstract

Objective—We determined the minimum mortality reduction that helicopter emergency medical services (HEMS) should provide relative to ground EMS for the scene transport of trauma victims to offset higher costs, inherent transport risks, and inevitable overtriage of minor injury patients.

Methods—We developed a decision-analytic model to compare the costs and outcomes of helicopter versus ground EMS transport to a trauma center from a societal perspective over a patient's lifetime. We determined the mortality reduction needed to make helicopter transport cost less than $100,000 and $50,000 per quality adjusted life year (QALY) gained compared to ground EMS. Model inputs were derived from the National Study on the Costs and Outcomes of Trauma (NSCOT), National Trauma Data Bank, Medicare reimbursements, and literature. We assessed robustness with probabilistic sensitivity analyses.

Corresponding Author: M. Kit Delgado, MD, MS, 117 Encina Commons, Stanford, CA 94305, kdelgado@stanford.edu.

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Results—HEMS must provide a minimum of a 17% relative risk reduction in mortality (1.6 lives saved/100 patients with the mean characteristics of the NSCOT cohort) to cost less than $100,000 per QALY gained and a reduction of at least 33% (3.7 lives saved/100 patients) to cost less than $50,000 per QALY. HEMS becomes more cost-effective with significant reductions in minor injury patients triaged to air transport or if long-term disability outcomes are improved.

Conclusions—HEMS needs to provide at least a 17% mortality reduction or a measurable improvement in long-term disability to compare favorably to other interventions considered cost-effective. Given current evidence, it is not clear that HEMS achieves this mortality or disability reduction. Reducing overtriage of minor injury patients to HEMS would improve its cost-effectiveness.

Introduction

Background

Trauma is the leading cause of death for United States (U.S.) residents aged 1-44, the most common cause of years of life lost for those under age 65,[1] and exacts $406 billion per year in costs, more than heart disease or cancer.[2,3] Survival after trauma is improved by timely transport to a trauma center for severely injured patients.[4] Helicopter emergency medical services (EMS) offer faster transport than ground EMS for patients injured far from trauma centers and is considered a preferred means of transport for critically injured patients.[5] Approximately 27% of US residents are dependent on helicopter transport in order to access Level I or II trauma center care within the “golden hour” from injury to emergency department arrival.[6] However, there are conflicting data to support routine use for scene transport. Most studies have concluded that helicopter transport was associated with improved survival,[7-23] while others showed no difference.[24-30] These studies have methodological limitations and suffer from selection bias, missing physiologic data, and heterogeneity in study settings and observational study designs.

Importance

In 2010 there were over 69,700 helicopter transports for trauma to U.S. Level I and II trauma centers; 44,700 (64%) were from the scene of injury.[31] Based on the Medicare Fee Schedule, insurance companies reimburse $5,000-$6,000 more per transport than ground ambulance which means up to $200-$240 million more were spent using this modality for trauma scene transport in 2010.[32] Furthermore, a systematic review has shown than more than half of the patients flown have minor or non-life-threatening injuries that would likely have similar outcomes if transported by ground.[33] Helicopter transport also may present a safety risk. In 2008, medical helicopter crashes caused 29 fatalities, the highest number to date, provoking federal review of the safety of air medical transport.[34] Currently, there is little empirical guidance on whether the routine use of helicopter EMS for trauma scene transport represents a good investment of critical care resources.

Goals of This Investigation

Given the limitations of the helicopter EMS outcomes literature, we aimed to determine the minimum reduction in mortality or long-term disability provided by helicopter EMS for its routine use to be considered cost-effective over ground EMS for the transport of patients from the scene of injury to a trauma center. We assessed these clinical thresholds relative to current evidence about effectiveness of helicopter transport. In this study, we account for transport costs and safety, as well as the inevitable overtriage of patients with minor injuries to helicopter transport.

Methods

Study Design

We developed a decision-analytic Markov model to compare the costs and outcomes of helicopter versus ground EMS trauma transport to a trauma center from a societal perspective over a patient lifetime. Clinical data and cost inputs were derived from the National Study on the Costs and Outcomes of Trauma (NSCOT)[4, 35] supplemented by the National Trauma Data Bank (NTDB),[36] Medicare reimbursements,[32] and the literature. We applied the model to a nationally-representative population of trauma victims (age 18-85) with a nationally-representative distribution of injury severities (minor to unsurvivable). The model follows patients from injury through transport, their hospitalization and first year post-discharge, and over the rest of their lifetimes.

The primary outcome was the threshold relative risk (RR) reduction in in-hospital mortality by helicopter EMS needed to achieve an incremental cost-effectiveness ratio compared to ground EMS below $100,000 per quality-adjusted life year (QALY) gained, a threshold at which health care interventions are generally considered cost-effective in high-income countries.[37] QALYs measure both quality and quantity of life lived after a health care intervention. We also evaluated the threshold RR reduction needed to achieve incremental cost-effectiveness ratio less than $50,000 per QALY gained, a more conservative and widely cited threshold.[38] We assumed that the relative reduction in mortality from helicopter EMS would only apply to patients with serious injury as defined by at least one injury with an Abbreviated Injury Scale (AIS) score of 3 or greater.[4, 17, 23, 33] The AIS is a validated measure of injury severity that is assigned based on hospital discharge diagnosis codes and is used to calculate the overall Injury Severity Score (ISS).[39, 40] We assessed the robustness of our estimates with one-way and probabilistic sensitivity analyses of all model variables and adhered to the recommendations of the Panel on Cost-Effectiveness in Health and Medicine.[41]

Model Assumptions and Inputs

Model Structure—The model represents a single decision about whether to use helicopter or ground ambulance transport in the field followed by a series of consequences related to this decision (Figure 1). We assume that differences in costs and outcomes between helicopter and ground EMS are driven by differences in in-hospital survival (i.e. survival to hospital discharge) for severely-injured patients and in the probability of crashing en route to the hospital. In-hospital survival is the only outcome measured in virtually all helicopter EMS studies, primarily due to availability of data.

Distribution of Patient Baseline Characteristics—The model accounted for variation in the clinical outcomes and costs based on whether patients had serious or minor injuries. Patients were determined to have to have a serious injury if there was at least one injury with an AIS score ≥ 3 and minor injuries if they had no injury with an AIS score ≥ 3. The probabilities for whether a patient had minor or serious injuries were determined using data from the NTDB 2010 National Sample (See Appendix). The distinction of minor versus serious injuries was necessary in order to determine the "overtriage" rate. HEMS "overtriage" is defined as patients with minor injuries who are transported by HEMS to trauma centers. These patients are not expected to have improved outcomes if transported by helicopter to a trauma center. In 2010, based on our analysis of the NTDB, the average national overtriage rate was 47%, but this rate varied greatly by center from 18 to 68% (See eTable 1). Patients transported by EMS with only minor injuries had an in-hospital death rate of 1.3%.

The distribution of population characteristics came from data obtained from the National Study of Costs and Outcomes after Trauma (NSCOT). NSCOT was a multicenter prospective study of 5,191 patients with serious injury treated at trauma centers and non-trauma centers in the United States.[4,35] Data was gathered from published studies and additional primary cost data were provided to us by NSCOT investigators. NSCOT also contains data on in-hospital and 1-year survival, costs, and quality of life using the SF-6D instrument. Based on published data from NSCOT, patients with serious injury have a mean in-hospital mortality rate of 7.6% with a range of 2.3% for patients with a maximum AIS score of 3 to 30.2% for patients with a maximum AIS score of 5-6. All model input assumptions are presented in Table 1.

Transport Assumptions—For our base case, we assumed patients are injured on average 55 miles (straight-line distance) away from the trauma center based on the estimated mean distance traveled by helicopter scene transports taken to U.S. trauma centers in the NTDB.[19] Given the wide regional variation in the costs and structure of EMS, costs per transport were standardized from the 2010 Medicare Fee Schedule, and were adjusted to take into account the difference between longer road distances compared with the straight-line distances traveled by helicopters (See Appendix).[42]

Helicopter and ground ambulance safety were modeled as a risk of fatal crash per vehicle mile traveled.[43] Unfortunately, there are no reliable nationally-representative data on ground ambulance safety since crashes and distances traveled in operation are not uniformly reported.[43] To conservatively address the concerns with relative safety of helicopter transport, we used the best-case scenario for ground ambulance safety (i.e., the risk of a fatal crash for a commercial light truck) in the reference case analysis.[44] Our analysis included crewmember fatalities caused by a fatal crash as well as the cost of replacing the vehicle. We conducted sensitivity analyses around these assumptions.

Modeled Effect of Helicopter EMS on Reducing Mortality—The effectiveness of helicopter transport compared with ambulance transport was modeled as the differential probability of in-hospital death for patients with serious injuries (AIS 3-6). We assessed differences in costs and outcomes by EMS transport mode over a range of the RR reduction

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from 1.00 to 0.60 (or 40% risk reduction) since greater reductions would be very unlikely (Further details in Appendix).

Health Care Expenditures Through First Year Post-Injury—Costs for patients with serious and minor injury treated at U.S. trauma centers were derived using NSCOT cost data. For seriously-injured patients, we considered the cost of hospitalization as well as post-hospitalization care (re-hospitalization, long term care, rehabilitation, outpatient care, and informal care). It also takes into account the differential in costs for patients who die in the hospital compared with those who are discharged alive. To derive costs for minor injury patients taken to U.S. trauma centers, we analyzed cost data from 993 patients excluded from the published NSCOT studies[4] due to having minor injuries (maximum AIS 1-2) to determine the mean cost of trauma center care for this group. We used previously described methods for analyzing the cost data from NSCOT.[45]

Projected Lifetime Survival and Costs—A Markov model was used to project incremental differences in lifetime survival and health care expenditures beyond 1-year post-injury (Figure 1). We assumed that mode of EMS transport does not affect survival beyond the initial hospitalization since there have been no studies evaluating transport mode survival beyond hospitalization. U.S. life tables were used to calculate remaining life expectancy.[46] Mortality rates derived from the life tables were adjusted to reflect decreased survival after major trauma based on a 10-year longitudinal study of trauma victims.[47] QALYs were calculated using the mean observed values of the SF-6D in the NSCOT cohort at 1-year post-injury (0.70).[48] As assumed in previous research, utilities were decreased over a lifetime proportional to differences in SF-6D scores by age reported for the general U.S. population.[48, 49] In our base case assumption, we assume that there is no difference in quality of life based on transport mode for patients that survive past one year,[50, 51] but we varied this assumption in sensitivity analysis. The Markov model was also used to project lifetime healthcare costs beyond 1-year based on Center for Medicaid and Medicare Services (CMS) age-specific estimates of annual healthcare expenditures.[52, 53] These costs were adjusted to account for the increased health expenditures of major trauma victims compared to the general U.S. population.[54] We applied an annual 3% discount rate to both QALYs and costs (See Appendix).[41]

Analysis

Helicopter and ground ambulance trauma transport were compared in terms of QALYs, total lifetime costs expressed in year 2009 dollars using the Gross Domestic Product deflator,[55] and incremental cost-effectiveness ratios (ICERs). ICERs were defined as the ratio of the total lifetime costs associated with transport by helicopter EMS minus the total lifetime costs associated with ground EMS divided by the difference between the lifetime QALYs after helicopter EMS and the QALYs after ground EMS. Robustness was assessed with one-way sensitivity analyses and probabilistic sensitivity analysis of all model inputs.

For our probabilistic sensitivity analyses, we performed 100,000 2nd order Monte Carlo simulation trials that selected values of all input parameters from the ranges described in Table 1 according to distributions that represent the uncertainty in their estimation (eTable

6). This allows for assessing the effect of the joint uncertainty across all parameters in the model on its estimated outcomes (See Appendix).[56] We then determined the RR reduction in mortality for helicopter EMS to cost less than $100,000/QALY gained in at least 95% of simulations (i.e. to have a least a 95% probability of being cost-effective at this threshold). All analyses were conducted using TreeAge Pro 2009 (TreeAge Software, Inc., Williamstown, MA) with input probability distributions verified using Stata 12.0 (StataCorp LP, College Station, TX).

Results

Using the base case assumptions, helicopter EMS needs to provide a 17% reduction in mortality (RR 0.83) for patients with serious injuries (AIS 3-6) to be below the threshold of $100,000/QALY gained (Figure 2A). Given the baseline in-hospital mortality of 7.6% for the base case, a 17% RR reduction equates to a 1.6% reduction in absolute mortality. Thus, helicopter EMS would have to save a minimum of 1.6 lives per 100 patient transports with mean characteristics of the NSCOT cohort in order to be cost-effective. Helicopter EMS would need to reduce mortality by an even larger amount, 33% (RR 0.67) or save more than 3.7 lives per 100 transports, to cost less than $50,000/QALY gained.

These findings assume the “overtriage rate” (patients with minor injuries who were triaged to helicopter EMS) was equal to the national average for U.S. Level I/II trauma centers (47%). Across U.S. regions, there is variability in the overtriage rate from 18% to 68%. Our results are sensitive to this variability (Figure 2B). In the region with the lowest overtriage rate (18%), only a 12% reduction in mortality (RR 0.88) would be needed for helicopter EMS to cost less than $100,000/QALY. Conversely, in the region with the highest overtriage rate (68%), the threshold is much higher with a needed mortality reduction of 25% (RR 0.75)

The cost-effectiveness of helicopter transport depends heavily on assumptions about whether there are differences in long-term patient disability outcomes by transport mode (Figure 2C). If helicopter EMS enabled a sustained improvement in quality of life by 0.01 on the SF-6D utility scale over the course of a lifetime, helicopter transport would be cost-effective at $94,100/QALY. However, if helicopter transport survivors were found to have a lower quality of life by 0.01 compared with ground ambulance survivors, helicopter EMS would need to provide at least a 29% reduction in mortality (RR 0.71) to cost less than $100,000/QALY.

The cost-effectiveness of helicopter transport decreases as the marginal cost of helicopter transport over ground transport increases from the base-case assumption of $5,700 (Figure 3). However, even if helicopter transport costs $10,000 more per transport than ground transport, as it might in rural areas with low flight volume, it would cost less than $100,000/QALY if mortality reductions of more than 25% could be achieved.

Our findings did not change across the range of uncertainty in how much more likely helicopter EMS has a fatal crash during transport (eFigure 3). Table 2 summarizes the relative mortality reduction for patients with serious injuries (AIS 3-6) needed for helicopter

EMS to be cost-effective according to various scenarios and cost-effectiveness thresholds. Table 2 also shows the number of lives helicopter EMS needs to save per 100 transports of patients with *serious injury*, the population whose outcomes may potentially be sensitive to helicopter versus ground EMS. This number ranged from the lowest value of 0 in the case of helicopters being associated with lower long-term disability to 3.7 in the case where the incremental costs of a helicopter versus ground transport was $15,000.

Results of probabilistic sensitivity analyses

In order for helicopter EMS to have a 95% probability of being cost-effective at a $100,000/QALY threshold given the joint uncertainty of all model parameters, a mortality reduction of 28% (RR 0.72; 3.0 lives saved per 100 patients with serious injury) would be needed (Figure 4).

Limitations

Given that there have been no previous studies comparing the long-term costs and outcomes by EMS transport mode, this analysis has a number of limitations. The decision model required certain assumptions and employed data from national datasets and numerous published studies. The results and conclusions are therefore specific to those assumptions and data. For example, baseline mortality probabilities and hospitalization costs inputs were derived from NSCOT in which most trauma centers were located in urban and suburban areas. Although we conducted sensitivity analyses around these assumptions, baseline mortality probabilities and costs may be different for injured patients taken rural trauma centers not represented in NSCOT.

Second, we focus on the average patient requiring trauma center care from NSCOT, as the outcomes and costs of such patients are already published. Results further stratified by age and injury severity are not yet available, though they can be incorporated into the model as soon as they are published. We speculate that the relative mortality reduction needed for helicopter transport to be cost-effective would need to be higher for older patients, and that the reduction needed for the transport of more severely injured patients could be lower, though the relative magnitude of these effects remains to be assessed.

Third, the analyses also assume that ground ambulances can leave their local area for long-distance transport without undue consequences in terms of decreased coverage for responding to other emergencies. In practice, many ground ambulances crews in rural areas where EMS coverage is sparse are reluctant to perform long-distance transports.[57] Thus, our results are most relevant to situations in which long-distance ground ambulance transport can be performed without causing decrements in EMS response to other emergencies in that area. Likewise, the base case costs per transport assume equal *existing* availability of ground and helicopter EMS for transport. While our sensitivity analysis assesses how our results would change based on a wide range in the marginal difference between helicopter and ground EMS transport costs, we do not explicitly model the regional variation in EMS system costs. Indeed, in areas where ground EMS coverage is non-existent, fully replacing helicopter EMS coverage would require up to six new ground EMS vehicles resulting in substantially higher costs per ground transport for the same number of patients transported.[58]

Discussion

Compared to ground EMS transport, helicopter scene transport is cost-effective if it results in a reduction in the relative risk of death for seriously injured trauma patients of at least 17% given our model assumptions. This translates into the need to save at least 1.6 lives per 100 patients transported with serious injury. Given current uncertainties, helicopter EMS must reduce mortality by more than 28% (3.0 lives per 100 transports with serious injury) to have a 95% probability of being cost-effective at less than $100,000/QALY gained. To meet the more conservative threshold of costing less than $50,000/QALY gained, helicopter EMS needs to reduce mortality by 33%.

There is one other study on the cost-effectiveness of helicopter EMS for trauma in the United States. [59] However, this study did not calculate incremental cost-effectiveness ratios from a societal perspective over a lifetime horizon as recommended by the U.S. Panel of Cost-Effectiveness in Health and Medicine, which limits its validity.[41]

It is not clear whether the current practice of helicopter scene transport meets the minimum threshold mortality reduction for helicopter transport defined in this study. While some studies of helicopter transport meet this threshold, all are observational, and most have major methodological limitations. Importantly, almost all previous helicopter transport studies are limited by the fact that the majority of patients in the ground EMS control group may not have been eligible for helicopter EMS since they may have been injured too close to the hospital.[7-23] Not excluding ground EMS patients injured close to the trauma center, who are less likely to die in the field than those who are injured far away and survive to be transported,[60] likely biases outcomes in favor of helicopter EMS.[61, 62]

A systematic review of studies attempted to risk adjust for the population heterogeneity seen in these studies and estimated that on average helicopter EMS saves 2.7 lives per 100 transports.[63] However, the risk adjustment tool used (TRISS: Trauma Score - Injury Severity Score) has extensive limitations,[64] and this study excluded several relevant studies that used logistic regression models.

The largest and most rigorous multicenter study to date is a retrospective analysis of 223,475 transports in the NTDB which estimated that helicopter EMS was associated with a 16% increase in the odds of survival (odds ratio [OR] 1.16; 95% CI, 1-1.14-1.17) or 1.5 lives saved per 100 patients with severe injury (95% CI: 1.4-1.6) taken to Level I trauma centers.[23] Even after risk adjustment, the study also found that survivors of helicopter EMS were less likely to be discharged home without services (48% vs. 57%; P<0.001) than survivors of ground EMS.[23] These results indicate helicopter survivors likely had worse disability outcomes than ground EMS survivors. If survivors of helicopter EMS have relatively worse disability outcomes, such as being less likely to survive neurologically intact, we found a much higher mortality reduction is needed (29% - Figure 2C) for helicopter EMS to be considered cost-effective. The authors also performed a sensitivity analysis excluding ground transports likely not eligible for helicopter transport based on available data on transport time and found the estimated survival benefit was cut in half from 16% to 7% (OR 1.07; 95% CI 1.04-1.17).[61, 62] This further suggests that use of helicopter EMS for transport to most trauma centers in this study was not cost-effective.

A recent Oklahoma trauma registry study found that helicopter EMS was associated with a reduction in 2-week mortality of 33% (HR 0.67 [95% CI: 0.54-0.84]) for patients with serious injury.[22] Another study of 10,314 patients with moderate to severe head injury (AIS ≥3) with a baseline mortality rate of 23% transported to five San Diego trauma centers found that helicopter EMS was associated with an adjusted odds ratio of 1.90 for hospital survival (95% CI: 1.60-2.20) and an adjusted odds ratio for discharge home without services of 1.36 (95% CI: 1.18-1.58). While these estimates appear to meet or exceed the risk reductions needed for helicopter EMS cost-effectiveness, both studies are limited by selection bias since they did not exclude the majority of ground EMS transports that were likely ineligible for helicopter EMS because they were injured too close to the hospital.

Finally, a recent secondary analysis of Resuscitation Outcomes Consortium (ROC) data collected to evaluate outcomes of severe injury did not find a significant association between helicopter EMS and 28-day survival (odds ratio 1.11 [95% CI: 0.82-1.51]).[30] Other studies have found either no benefit from helicopter EMS[24-29] or are subject to the same methodological limitations outlined above.[7-21]

In summary, there is limited evidence in the comparative effectiveness literature to conclude that helicopter EMS is cost-effective relative to ground EMS for most patients in the U.S given current rates of overtriage. Whether helicopter EMS is cost-effective for certain age and injury subgroups remains to be answered in future research. This study is the first to define the clinical benefit needed to make helicopter transport cost-effective relative to ground ambulance for trauma.

Our study also highlights the impact that differences in disability outcomes can have on cost-effectiveness. We found that any measurable improvement in long-term disability outcomes would make helicopter transport cost-effective even if no lives were saved relative to ground transport.

This is also the first cost-effectiveness analysis that takes into account the high proportion of patients who are triaged to helicopter EMS who only have minor injuries. Although a proportion of these minor injury patients require air medical transport due to logistical and topographic considerations, minor injury patients who are unnecessarily transported by helicopter cannot be expected to have improved outcomes despite the greater expense.

Our findings also imply that reducing overtriage of minor injury to helicopter EMS is the most promising avenue for increasing the cost-effectiveness of this critical care intervention. For example, the outcomes after activating helicopter EMS based on crash mechanism only, or routine use of helicopter "auto-launch" at the time of the 911 call instead of after local EMS assessment at the scene should be further scrutinized as these practices likely lead to overtriage. Our model also implies the value of helicopter EMS needs to be evaluated on a regional and geographic basis. For example, a rural region that has a high cost of helicopter transport due to low flight volume (e.g. <400 transports per year with a cost per transport of $10,000) could potentially offset this high cost of transport by ensuring that seriously injured patients are transported by helicopter to a trauma center. Since mortality for rural trauma is twice as high as in urban areas, this may represent a cost-effective opportunity for improvement.[60, 65, 66]

We also found that current helicopter crash rates do not impact cost-effectiveness, except when there is very little clinical benefit from helicopter transport, because the probability of helicopter is crash is still very low. This is the case even though we assume the best-case scenario for ground transport, that they have a minimum fatal crash risk comparable to commercial light trucks. In reality, ground ambulance crash risks are likely higher especially during lights-and-sirens operations.

In existing U.S. EMS systems where both ground and helicopter transport from the scene of injury are feasible, helicopter EMS must reduce mortality by at least 17% to compare favorable to other healthcare interventions considered cost-effective. Helicopter EMS would also be considered cost-effective with smaller mortality reductions as long an improvement in long-term disability outcomes is also demonstrated. It is not clear from the literature that helicopter EMS achieves this threshold mortality reduction, leaving its cost-effectiveness in doubt relative to ground EMS for the majority of U.S patients transported to trauma centers. Reducing the overtriage of minor injury patients to helicopter EMS is a promising avenue for improving its cost-effectiveness. Further rigorous study of the health outcomes of helicopter EMS, including the impact of helicopter transport on long-term disability, is needed to better assess the value of this frequently used, critical care intervention in the U.S.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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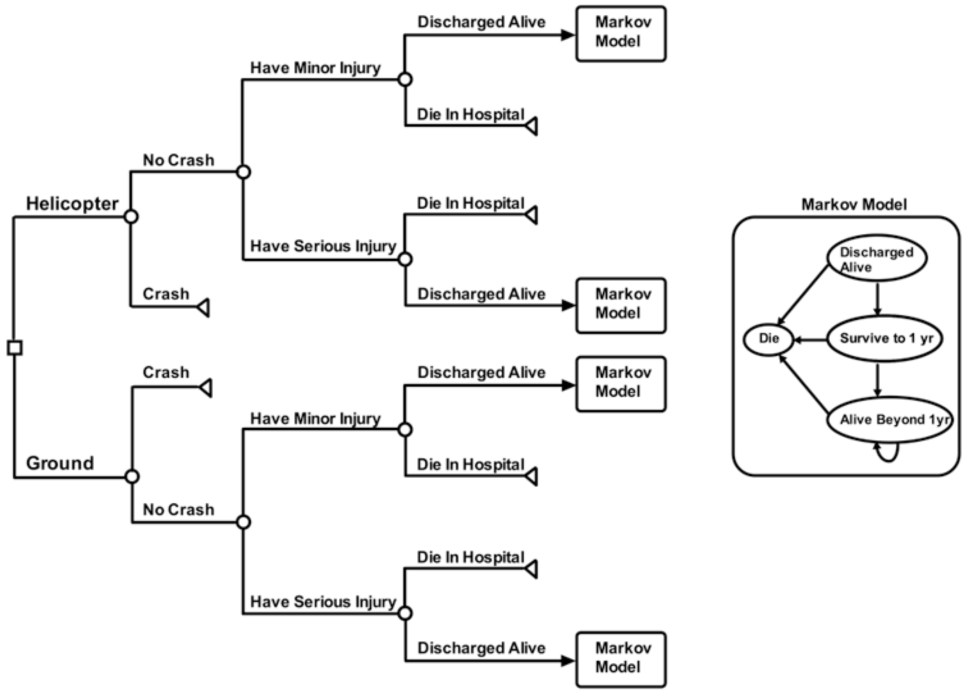

Figure 1. Model structure

The model calculates the difference in the costs and outcomes related to the decision of choosing helicopter EMS as opposed to ground EMS for the scene transport of an injured patient to a U.S. trauma center. Event probabilities and their associated costs conditional on strategy chosen (helicopter vs. ground) and injury severity are presented in Table 1. A Markov model was used to calculate remaining patient life expectancy and lifetime health care expenditures for the cohort of patients who survive to be discharged from the hospital.

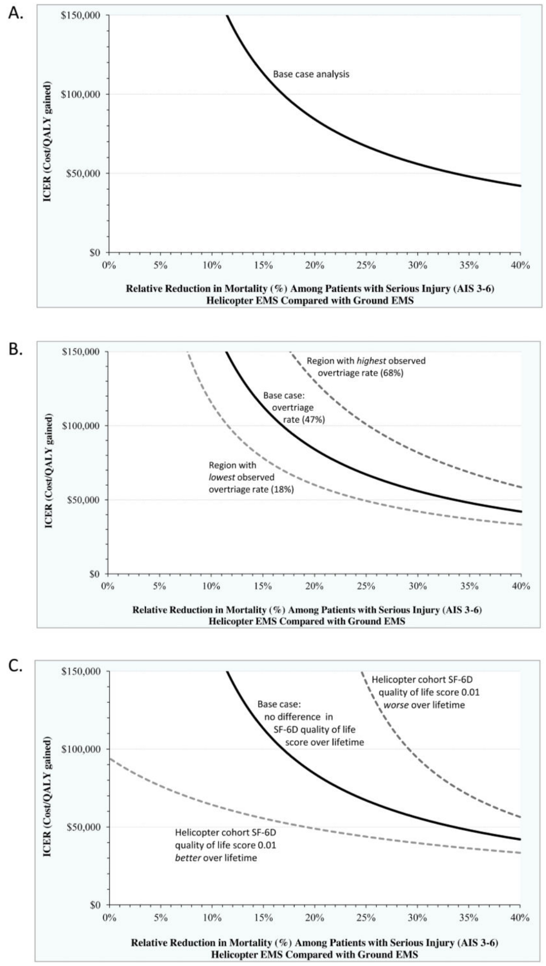

Figure 2. Relationship between relative reduction in mortality and the cost-effectiveness of helicopter EMS

ICER: incremental cost-effectiveness ratio. *AIS:* Abbreviated Injury Scale. **2A) Base case analysis.** The plotted line represents the cost-effectiveness of helicopter EMS relative to ground EMS as a function of the assumed mortality reduction provided by helicopter EMS given the base case assumptions described in Table 1. **2B) Effect of overtriage rate on cost-effectiveness of helicopter EMS.** Based on analysis of national data, 47% of patients transported by helicopter EMS have only minor injuries. The two dotted lines demonstrate how the cost-effectiveness of helicopter EMS changes based on the highest and lowest regional overtriage rates observed in national data. **2C) Effect of difference in disability outcomes on cost-effectiveness of helicopter EMS.** In our base case, we assume no difference in disability outcomes. The two dotted lines demonstrate how the cost-effectiveness of helicopter EMS changes based on whether helicopter EMS is associated with worse or better disability outcomes as measured by the SF-6D quality of life scale over the course of a lifetime.

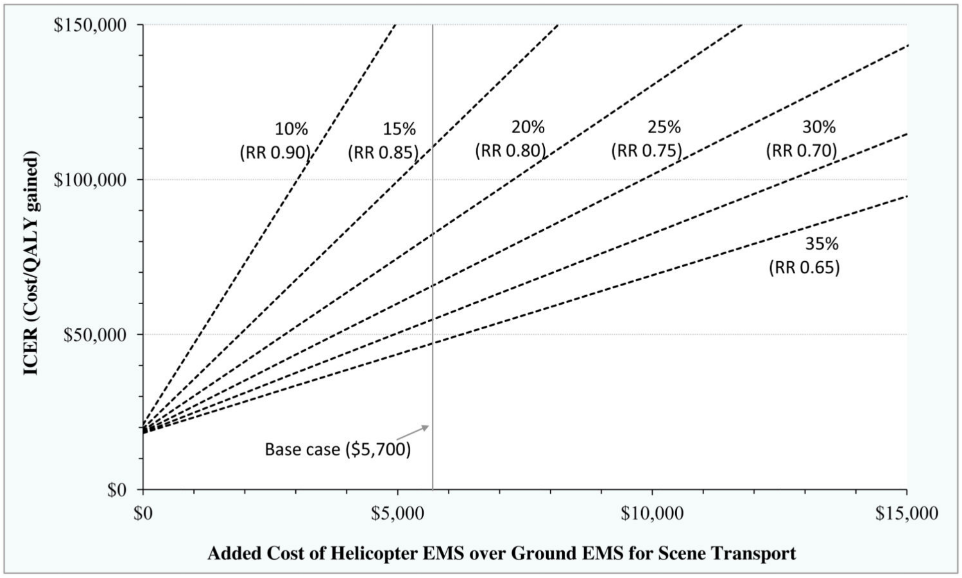

Figure 3. Effect of the variation in the added cost of helicopter EMS on the threshold mortality reduction needed to be cost-effective

ICER: incremental cost-effectiveness ratio. *RR*: relative risk ratio. Based on the Medicare Fee Schedule, we assume that the helicopter EMS costs about $5,700 more than ground EMS transport for patients located 55-miles from a trauma center (our base case assumption). The plotted lines demonstrate how the cost-effectiveness of helicopter EMS would change based on the assumed relative mortality reduction and the regional variation in the added cost of helicopter EMS over ground EMS.

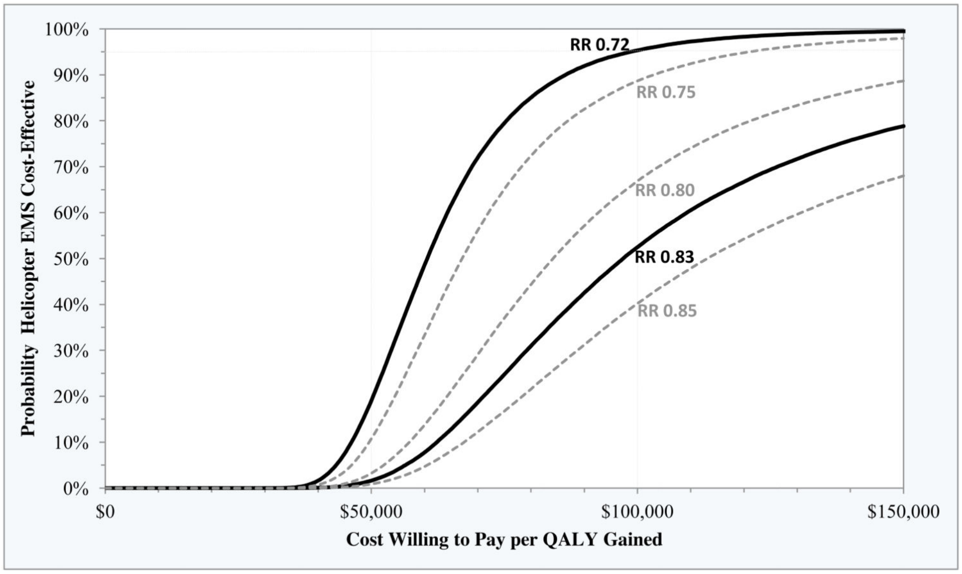

Figure 4. Probabilistic sensitivity analysis of the incremental cost-effectiveness ratio of helicopter EMS versus ground EMS for trauma scene transport according to the size of the relative mortality reduction from helicopter EMS

A threshold mortality reduction of ≥28% (RR 0.72) is needed for helicopter EMS to be cost-effective in ≥ 95% of simulations if society is willing to pay $100,000 per QALY gained. This is a higher threshold mortality reduction than the threshold of 17% (RR 0.83) that was determined using base-case assumptions. The threshold of 17% (RR 0.83) was cost-effective in 52% of simulations if society is willing to pay $100,000 per QALY gained.

Table 1

Model input assumptions

Variable	Base-Case Value	Range for Sensitivity Analysis	Reference
Distribution of Cohort Characteristics			
Age (%)		N/A	MacKenzie[4]
18-54 yr	72		
55-64 yr	11		
65-74 yr	8		
75-85 yr	9		
Male (%)	69	N/A	MacKenzie[4]
Maximal Abbreviated Injury Scale (AIS) score (%):		N/A	MacKenzie[4] NTDB 2010 analysis
"Minor Injury" Subgroup			Newgard[67]
AIS 1 (minor)	21		
AIS 2 (moderate)	26		
"Serious Injury" Subgroup			
AIS 3 (serious)	31		
AIS 4 (severe)	16		
AIS 5-6 (critical-unsurvivable)	6		
Transport Assumptions			
Mean distance traveled by helicopters for trauma scene transports in the U.S. (miles)	55	25-85	Brown,[19] Carr[68]
Probability of fatal helicopter crash in 55-mile transport	0.000009	0.0000033-0.000046	Blumen[43]
Probability of a fatal ambulance crash in 55-mile transport	0.00000034	0-0.0000015	NHTSA[44]
Helicopter cost per transport, by distance from trauma center ($)			Medicare[32]
25 miles	5,800	5,400-6,800	
55 miles (base case)	6,800	6,400-7,800	
85 miles	7,800	7,400-8,800	
ALS ground ambulance cost per transport by distance trauma center, adjusted for longer road distance ($)			Medicare[32] Diaz[36]
25 miles	900	800-1,000	
55 miles (base case)	1,100	1,000-1,300	
85 miles	1,400	1,300-1,600	
Cost to replace helicopter if crashes ($)	4,200,000	3,000,000-5,000,000	Retail website[69]
Cost to replace ambulance if crashes ($)	108,000	80,000-140,000	Retail website[70]
QALYs lost in helicopter crash	120		Assumption
QALYs lost in ground ambulance crash	30		Assumption
Clinical Assumptions			
Serious Injury Subgroup			
Mean baseline probability of in-hospital death	0.076	0.056-0.096	MacKenzie[4]
Relative risk ratio (RR) for in-hospital mortality from helicopter EMS relative to ground EMS transport (1.00 = no difference)	N/A	1.00-0.60	Ringburg,[63] Thomas,[71-73] Brown,[19, 74] Taylor,[75]

Variable	Base-Case Value	Range for Sensitivity Analysis	Reference
			Davis,[17] Stewart,[22] Bulger,[30], Galvagno Jr[23]
Mean probability of dying in 1 year, conditional on being discharged alive	0.030	0.010-0.050	MacKenzie[4]
1-year mean utility state (quality of life) after major trauma	0.70	N/A	MacKenzie[48]
1-year mean utility difference between helicopter vs. ground ambulance survivors	0	-0.01, 0.01	Ringburg,[51] Brazier[50]
Yearly mortality rates beyond 1-yr post-injury	US life tables	N/A	CDC[46]
Mean mortality hazard ratio for decreased lifetime survival	5.19	4.2-6.2	Cameron[47, 74]
Yearly decrease in quality of life over lifetime	N/A	N/A	Hanmer[49]
Minor Injury Subgroup			
Mean baseline probability of in-hospital death	0.013	0.010-0.015	NTDB analysis
Relative risk ratio (RR) for in-hospital mortality from helicopter EMS relative to ground EMS transport (1.00 = no difference)	1.00	N/A	Ringburg[63], Thomas[71, 72] Taylor[73] Galvagno Jr[23]
Mean probability of dying in 1 year, conditional on being discharged alive	0.013	0.010-0.015	Assumption based on MacKenzie[4]
1-yr mean utility state (quality of life) after minor trauma	0.80	N/A	Polinder[76]
1-yr mean utility difference between helicopter vs. ground ambulance survivors	0	-0.01, 0.01	Ringburg,[51] Brazier[50]
Yearly mortality rates beyond 1-yr post-injury	US life tables	N/A	CDC[46]
Mean mortality hazard ratio for decreased lifetime survival	1.38	1.22-1.55	Cameron[47]
Yearly decrease in quality of life over lifetime	N/A	N/A	Hanmer[49]
Cost Assumptions			
Serious Injury Subgroup			
Cohort mean cost of hospitalization if discharged alive ($)	59,200	54,500-63,900	NSCOT analysis, MacKenzie,[48] Weir[45]
Cohort mean cost of hospitalization if die in hospital ($)	50,700	45,400-56,000	NSCOT analysis, MacKenzie,[48] Weir[45]
Cohort mean 1-yr treatment costs following discharge from index hospitalization ($)	35,400	33,000-38,000	NSCOT analysis, MacKenzie,[48] Weir[45]
Yearly healthcare costs beyond 1-yr post-injury	N/A	N/A	CMS[53]
Hazard ratio for increased lifetime health care expenditures after major trauma	1.45	1.39-1.51	Cameron[54]
Minor Injury Subgroup			
Cohort mean cost of hospitalization ($); includes ED care for ED discharges	12,900	11,900-13,800	NSCOT analysis, Weir[45]
Cohort mean 1-yr treatment costs following discharge from index hospitalization ($)	9,300	8,300-10,200	Davis[76]
Yearly healthcare costs beyond 1-yr post-injury	N/A	N/A	CMS[53]
Hazard ratio for increased lifetime health care expenditures after major trauma	1.25	1.23-1.27	Cameron[54]
Annual discount rate for health expenditures and QALY's gained	0.03	N/A	Weinstein[41]

NTDB: National Trauma Data Bank; NHTSA: National Highway Traffic Safety Administration; ALS: Advanced Life Support; QALY: Quality Adjusted Life Year; CDC: Centers for Disease Control and Prevention; CMS: Centers for Medicare and Medicaid Services.

Table 2

Summary results of scenario analyses: minimum reduction in mortality amongst patients with *serious injury* triaged to helicopter EMS to be cost-effective relative to ground EMS

Scenario	Minimum Reduction in Mortality Amongst Patients with Serious Injury (AIS 3-6) Triaged to Helicopter EMS Scene Transport to be Cost-Effective Relative to Ground EMS*			
	$100,000 per QALY gained threshold		*$50,000* per QALY gained threshold	
	Relative Risk Ratio for Inhospital Mortality	Lives Needed to be Saved per 100 Transports (AIS 3-6)	Relative Risk Ratio for Inhospital Mortality	Lives Needed to be Saved per 100 Transports (AIS 3-6)
Base Case Analysis	***0.83***	***1.6***	***0.67***	***3.7***
Overtriage of Minor Injury Patients (Maximum AIS 1-2)				
Base Case Analysis (47%)	-	-	-	-
Perfect (0%)	0.90	0.8	0.79	2.0
Lowest observed region (18%)	0.88	0.9	0.76	2.4
Highest observed region (68%)	0.75	2.4	0.56	6.0
Difference in Disability Outcomes				
Base Case Analysis (No Difference)	-	-	-	-
Helicopter Better (0.01 higher SF-6D)	1.00	0	0.81	1.8
Helicopter Worse (0.01 lower SF-6D)	0.71	3.1	0.58	5.5
Added Per Transport Cost of Helicopter EMS Over Ground EMS				
Base Case Analysis ($5,700)	-	-	-	-
$3,000	0.90	0.8	0.79	2.0
$7,500	0.80	1.9	0.61	4.9
$10,000	0.75	2.5	0.54	6.5
$12,500	0.70	3.3	0.49	7.9
$15,000	0.67	3.7	0.44	9.7
Distance from Trauma Center				
Base Case Analysis (55 miles)	-	-	-	-
25 miles	0.85	1.3	0.69	3.4
85 miles	0.82	1.7	0.64	4.3

Assumes that there is a range of patients with minor injuries (AIS 1-2) also triaged to helicopter transport (Base Case Analysis = 47%, unless otherwise indicated) and that patients with minor injuries have no difference in outcomes conditional on transport mode.

AIS: Abbreviated Injury Scale; *QALY:* Quality adjusted life year