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

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

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 during 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 gained compared with ground EMS. Model inputs were derived from the National Study on the Costs and Outcomes of Trauma, National Trauma Data Bank, Medicare reimbursements, and literature. We assessed robustness with probabilistic sensitivity analyses.

Results: Helicopter EMS must provide a minimum of a 15% relative risk reduction in mortality (1.3 lives saved/100 patients with the mean characteristics of the National Study on the Costs and Outcomes of Trauma cohort) to cost less than $100,000 per quality-adjusted life-year gained and a reduction of at least 30% (3.3 lives saved/100 patients) to cost less than $50,000 per quality-adjusted life-year. Helicopter EMS becomes more cost-effective with significant reductions in patients with minor injury who are triaged to air transport or if long-term disability outcomes are improved.

Conclusion: Helicopter EMS needs to provide at least a 15% mortality reduction or a measurable improvement in long-term disability to compare favorably with other interventions considered cost-effective. Given current evidence, it is not clear that helicopter EMS achieves this mortality or disability reduction. Reducing overtriage of patients with minor injury to helicopter EMS would improve its cost-effectiveness. [Ann Emerg Med. 2013;62:351-364.]

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0196-0644/$-see front matter

http://dx.doi.org/10.1016/j.annemergmed.2013.02.025

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INTRODUCTION

Background

Trauma is the leading cause of death for US residents aged 1 to 44 years, is the most common cause of years of life lost for those younger than 65 years,[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) offers 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 to access Level I or II trauma center care within the "golden hour" from injury to emergency department (ED) 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] whereas others showed no difference.[24-30] These studies have methodological limitations and selection bias, missing physiologic data, and heterogeneity in study settings and observational study designs.

Importance

In 2010, there were more than 69,700 helicopter transports for trauma to US Level I and II trauma centers; 44,700 (64%) were from the scene of injury.[31] According to the Medicare Fee Schedule, insurance companies reimburse $5,000 to $6,000 more per transport than ground ambulance, which means $200 to $240 million more was spent with 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 transport were 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]

Editor's Capsule Summary

What is already known on this topic

Helicopter emergency medical services (EMS) are expensive compared with ground transport. The cost-benefit in terms of improved survival in trauma has not been established.

What question this study addressed

This decision analysis investigated the mortality reduction needed to make the cost-effectiveness of helicopter EMS transport comparable to that of other health care activities. National Study on Costs and Outcomes of Trauma and other databases were used as inputs to the model.

What this study adds to our knowledge

Helicopter EMS must provide a substantial (15%) relative risk reduction (1.3 lives saved/100 patients) to cost less than $100,000 per quality-adjusted life-year gained. The effect on acute morbidity was not studied.

How this is relevant to clinical practice

To be cost-effective, helicopter EMS would have to reduce the number of patients with minor injury transported or demonstrate that there are improvements in long-term disability that improve the balance sheet.

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.

MATERIALS AND 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 during 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,[36] Medicare reimbursements,[32] and the literature. We applied the model to a nationally representative population of trauma victims (aged 18 to 85 years) with a nationally representative distribution of injury severities (minor to unsurvivable). The model follows patients from injury through transport, their hospitalization and first year postdischarge, and during 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 with ground EMS below $100,000 per quality-adjusted life-year gained, a threshold at which health care interventions are generally considered cost-effective in high-income countries.[37] Quality-adjusted life-years 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 quality-adjusted life-year gained, a more conservative and widely cited threshold.[38] We assumed that the relative reduction in mortality from helicopter EMS would apply only to patients with serious injury, as defined by at least 1 injury with an Abbreviated Injury Score of 3 or greater.[4,17,23,33] The Abbreviated Injury Score is a validated measure of injury severity that is assigned according to hospital discharge diagnosis codes and is used to calculate the overall Injury Severity Score.[39,40] We assessed the robustness of our estimates with 1-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

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 assumed that differences in costs and outcomes between helicopter and ground EMS were driven by differences in inhospital survival (ie, survival to hospital discharge) for severely injured patients and in the probability of crashing en route to the hospital. Inhospital survival is the only outcome measured in virtually all helicopter EMS studies, primarily because of availability of data.

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 had a serious injury if there was at least 1 injury with an Abbreviated Injury Score greater than 3 and minor injuries if they had no injury with an Abbreviated Injury Score greater than 3. The probabilities for whether a patient had minor or serious injuries were determined with data from the National Trauma Data Bank 2010 National Sample (Appendix E1, available online at http://www.annemergmed.com). The distinction of minor versus serious injuries was necessary to determine the overtriage rate. Helicopter EMS overtriage is defined as patients with minor injuries who are transported by helicopter EMS to trauma centers. These patients are not expected to have

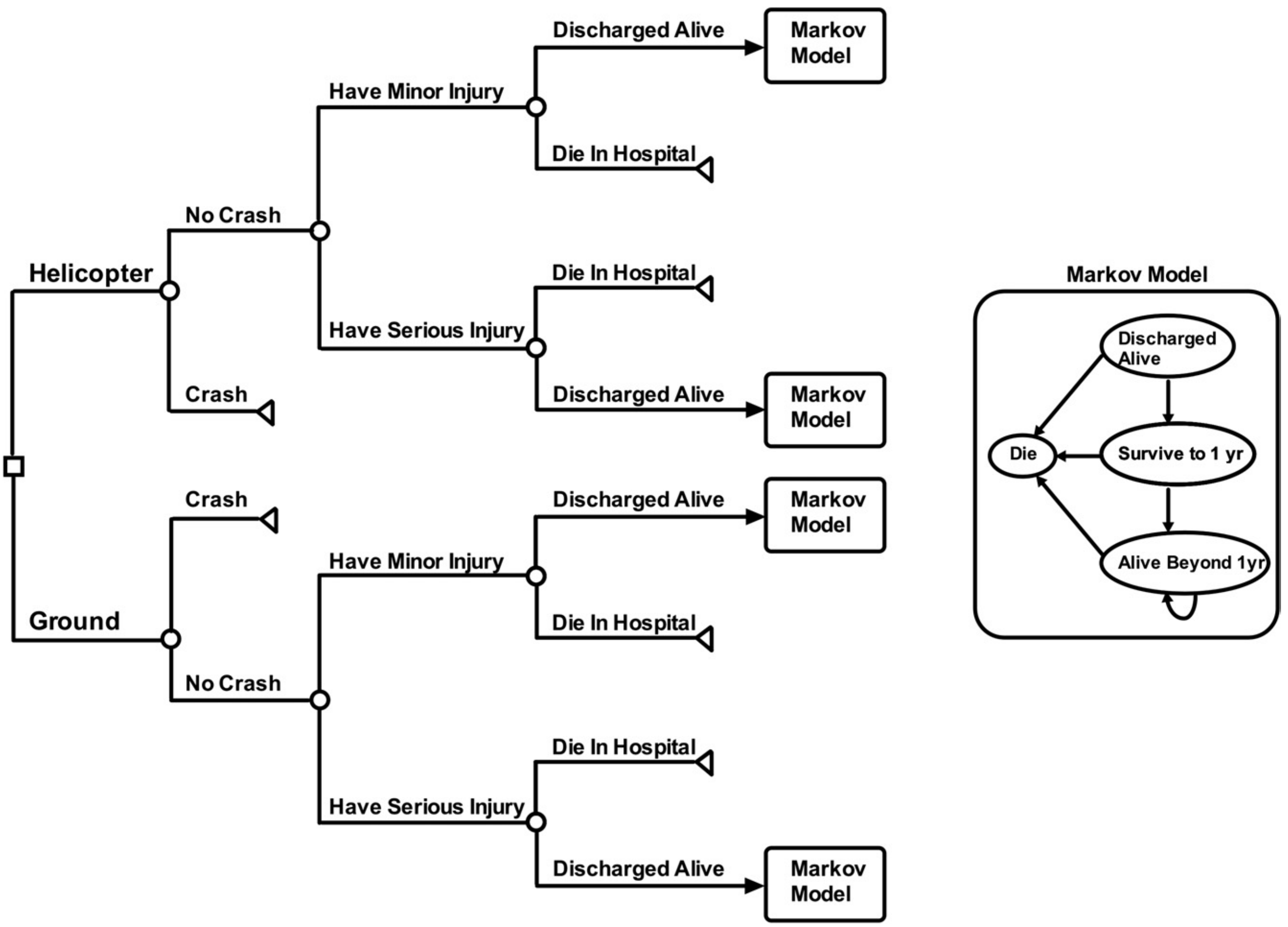


Figure 1. Model structure. The model calculates the difference in the costs and outcomes related to the decision of choosing helicopter EMS as opposed to ground EMS for the scene transport of an injured patient to a US trauma center. Event probabilities and their associated costs conditional on strategy chosen (helicopter versus 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.

improved outcomes if transported by helicopter to a trauma center. In 2010, according to our analysis of the National Trauma Data Bank, the average national overtriage rate was 36%, but this rate varied greatly by center, from 9% to 69% (Table E1, available online at http://www.annemergmed.com). Patients transported by EMS with only minor injuries had an inhospital death rate of 1.3%.

The distribution of population characteristics came from data obtained from the NSCOT, a multicenter prospective study of 5,191 patients with serious injury treated at trauma centers and nontrauma centers in the United States.[4,35] Data were gathered from published studies, and additional primary cost data were provided by NSCOT investigators. NSCOT also contains data on inhospital and 1-year survival, costs, and quality of life, using the SF-6D instrument. According to published data from NSCOT, patients with serious injury have a mean inhospital mortality rate of 7.6%, with a range of 2.3% for patients with a maximum Abbreviated Injury Score of 3 to 30.2% for patients with a maximum Abbreviated Injury Score of 5 to 6. All model input assumptions are presented in Table 1.

For our base case, we assumed that patients are injured on average 55 miles (straight-line distance) away from the trauma center, according to the estimated mean distance traveled by helicopter scene patients transported to US trauma centers in the National Trauma Data Bank.[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 (Appendix E1, available online at http://www.annemergmed.com).[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 because crashes and distances traveled in operation are not uniformly reported.[43] To conservatively

Table 1. Model input assumptions.

Variable	Base-Case Value	Range for Sensitivity Analysis	Reference
Distribution of cohort characteristics			
Age, %, y		N/A	MacKenzie[4]
18–54	72		
55–64	11		
65–74	8		
75–85	9		
Male, %	69	N/A	MacKenzie[4]
Maximal AIS, %		N/A	MacKenzie,[4] NTDB 2010 analysis, Newgard[67]
"Minor injury" subgroup			
AIS 1 (minor)	10		
AIS 2 (moderate)	26		
"Serious injury" subgroup			
AIS 3 (serious)	39		
AIS 4 (severe)	17		
AIS 5–6 (critical-unsurvivable)	8		
Transport assumptions			
Mean distance traveled by helicopters for trauma scene transports in the United States, 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 in miles from trauma center, $			Medicare[32]
25	5,800	5,400–6,800	
55 (base case)	6,800	6,400–7,800	
85	7,800	7,400–8,800	
ALS ground ambulance cost per transport by distance in miles from trauma center, adjusted for longer road distance, $			Medicare,[32] Diaz[36]
25	900	800–1,000	
55 (base case)	1,100	1,000–1,300	
85	1,400	1,300–1,600	
Cost to replace helicopter if crashes, $	4,200,000	3,000,000–5,000,000	Retail Web site[69]
Cost to replace ambulance if crashes, $	108,000	80,000–140,000	Retail Web site[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 inhospital death	0.076	0.056–0.096	MacKenzie[4]
RR ratio for inhospital 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] Davis,[17] Stewart,[22] Bulger,[30] Galvagno Jr.[23]
Mean probability of dying in 1 y, conditional on being discharged alive	0.030	0.010–0.050	MacKenzie[4]
1-y mean utility state (quality of life) after major trauma	0.70	N/A	MacKenzie[48]
1-y mean utility difference between helicopter vs ground ambulance survivors	0	−0.01, 0.01	Ringburg,[51] Brazier[50]
Yearly mortality rates beyond 1 y postinjury	US life tables	N/A	CDC[46]

address the concerns with relative safety of helicopter transport, we used the best-case scenario for ground ambulance safety (ie, 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.

The effectiveness of helicopter transport compared with ambulance transport was modeled as the differential probability of inhospital death for patients with serious injuries

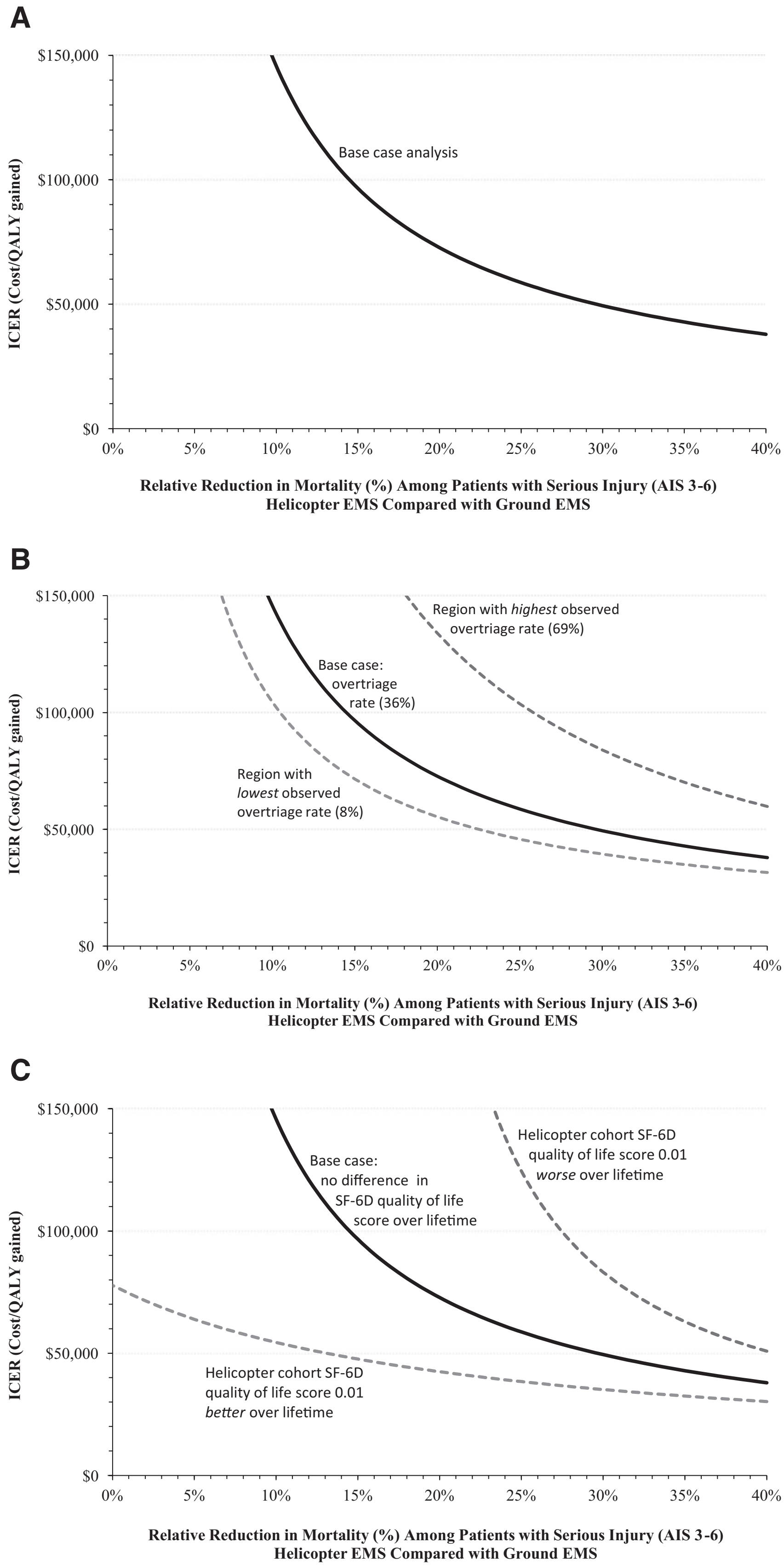
Table 1. Continued.

Variable	Base-Case Value	Range for Sensitivity Analysis	Reference
Mean mortality hazard ratio for decreased lifetime survival	5.19	4.2–6.2	Cameron[47,74]
Yearly decrease in quality of life during lifetime	N/A	N/A	Hanmer[49]
Minor injury subgroup			
Mean baseline probability of inhospital death	0.013	0.010–0.015	NTDB analysis
RR ratio for inhospital 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 y, conditional on being discharged alive	0.013	0.010–0.015	Assumption based on MacKenzie[4]
1-y mean utility state (quality of life) after minor trauma	0.80	N/A	Polinder[76]
1-y mean utility difference between helicopter vs ground ambulance survivors	0	−0.01, 0.01	Ringburg,[51] Brazier[50]
Yearly mortality rates beyond 1 y postinjury	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 during 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 death in hospital, $	50,700	45,400–56,000	NSCOT analysis, MacKenzie,[48] Weir[45]
Cohort mean 1-y treatment costs after discharge from index hospitalization, $	35,400	33,000–38,000	NSCOT analysis, MacKenzie,[48] Weir[45]
Yearly health care costs beyond 1 y postinjury	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-y treatment costs after discharge from index hospitalization, $	9,300	8,300–10,200	Davis[77]
Yearly health care costs beyond 1 y postinjury	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 QALYs gained	0.03	N/A	Weinstein[41]

AIS, Abbreviated Injury Score; *NTDB*, National Trauma Data Bank; *NHTSA*, National Highway Traffic Safety Administration; *ALS*, advanced life support; *QALY*, quality-adjusted life-year; *RR*, relative risk; *CDC*, Centers for Disease Control and Prevention; *NSCOT*, National Study on the Costs and Outcomes of Trauma; *CMS*, Centers for Medicare & Medicaid Services; *ED*, Emergency Department.

(Abbreviated Injury Score 3 to 6). We assessed differences in costs and outcomes by EMS transport mode over a range of the RR reduction, from 1.00 to 0.60 (or 40% risk reduction), because greater reductions would be very unlikely (further details in Appendix E1, available online at http://www.annemergmed.com).

Costs for patients with serious and minor injury treated at US trauma centers were derived with NSCOT cost data. For seriously injured patients, we considered the cost of hospitalization, as well as posthospitalization care (rehospitalization, 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 patients with minor injury who were taken to US trauma centers, we analyzed cost data from 993 patients excluded from the published NSCOT studies[4] because of having minor injuries (maximum Abbreviated Injury Score 1 to 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]


A
$150,000
$100,000
$50,000
$0
ICER (Cost/QALY gained)
Base case analysis
0%
5%
10%
15%
20%
25%
30%
35%
40%
Relative Reduction in Mortality (%) Among Patients with Serious Injury (AIS 3-6)
Helicopter EMS Compared with Ground EMS
B
$150,000
$100,000
$50,000
$0
ICER (Cost/QALY gained)
Region with highest observed overtriage rate (69%)
Base case: overtriage rate (36%)
Region with lowest observed overtriage rate (8%)
0%
5%
10%
15%
20%
25%
30%
35%
40%
Relative Reduction in Mortality (%) Among Patients with Serious Injury (AIS 3-6)
Helicopter EMS Compared with Ground EMS
C
$150,000
$100,000
$50,000
$0
ICER (Cost/QALY gained)
Helicopter cohort SF-6D quality of life score 0.01 worse over lifetime
Base case: no difference in SF-6D quality of life score over lifetime
Helicopter cohort SF-6D quality of life score 0.01 better over lifetime
0%
5%
10%
15%
20%
25%
30%
35%
40%
Relative Reduction in Mortality (%) Among Patients with Serious Injury (AIS 3-6)
Helicopter EMS Compared with Ground EMS

A Markov model was used to project incremental differences in lifetime survival and health care expenditures beyond 1-year postinjury (Figure 1). We assumed that mode of EMS transport does not affect survival beyond the initial hospitalization because there have been no studies evaluating transport mode survival beyond hospitalization. US 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 according to a 10-year longitudinal study of trauma victims.[47] Quality-adjusted life-years were calculated with the mean observed values of the Short Form-6 Dimension (SF-6D) scale in the NSCOT cohort at 1 year postinjury (0.70).[48] As assumed in previous research, utilities were decreased during a lifetime proportional to differences in SF-6D scores by age reported for the general US population.[48,49] In our base case assumption, we assumed that there was no difference in quality of life according to transport mode for patients who survive past 1 year,[50,51] but we varied this assumption in sensitivity analysis. The Markov model was also used to project lifetime health care costs beyond 1 year according to Centers for Medicare & Medicaid Services age-specific estimates of annual health care expenditures.[52,53] These costs were adjusted to account for the increased health expenditures of major trauma victims compared with the general US population.[54] We applied an annual 3% discount rate to both quality-adjusted life-years and costs (Appendix E1, available online at http://www.annemergmed.com).[41]

Analysis

Helicopter and ground ambulance trauma transport were compared in terms of quality-adjusted life-years, total lifetime costs expressed in 2009 dollars using the Gross Domestic Product deflator,[55] and incremental cost-effectiveness ratios, which 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 quality-adjusted life-years after helicopter EMS and the quality-adjusted life-years after ground EMS. Robustness was assessed with 1-way sensitivity analyses and probabilistic sensitivity analysis of all model inputs.

For our probabilistic sensitivity analyses, we performed 100,000 second-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 (Table E6, available online at http://www.annemergmed.com). This allows for assessing the effect of the joint uncertainty across all parameters in the model on its estimated outcomes (Appendix E1, available online at http://www.annemergmed.com).[56] We then determined the RR reduction in mortality for helicopter EMS to cost less than $100,000 per quality-adjusted life-year gained in at least 95% of simulations (ie, to have a least a 95% probability of being cost-effective at this threshold). All analyses were conducted with TreeAge Pro Suite 2009 (TreeAge Software, Inc., Williamstown, MA), with input probability distributions verified with Stata (version 12.0; StataCorp, College Station, TX).

RESULTS

Using the base case assumptions, helicopter EMS needs to provide a 15% reduction in mortality (RR 0.85) for patients with serious injuries (Abbreviated Injury Score 3 to 6) to be below the threshold of $100,000 per quality-adjusted life-year gained (Figure 2*A*). Given the baseline inhospital mortality of 7.6% for the base case, a 15% RR reduction equates to a 1.3% reduction in absolute mortality. Thus, helicopter EMS would have to save a minimum of 1.3 lives per 100 patient transports with mean characteristics of the NSCOT cohort to be cost-effective. Helicopter EMS would need to reduce mortality by an even larger amount, 30% (RR 0.70), or save more than 3.3 lives per 100 transports to cost less than $50,000 per quality-adjusted life-year gained.

These findings assume that the overtriage rate (patients with minor injuries who were triaged to helicopter EMS) was equal to the national average for US Level I or II trauma centers (36%). Across US regions, there is variability in the overtriage rate from 9% to 69%. Our results are sensitive to this variability (Figure 2*B*). In the region with the lowest overtriage rate (9%), only a 11% reduction in mortality (RR 0.89) would be needed for helicopter EMS to cost less than $100,000 per quality-adjusted life-year. Conversely, in the region with the highest overtriage rate (69%), the threshold is much higher, with a needed mortality reduction of 26% (RR 0.74).

The cost-effectiveness of helicopter transport depends heavily on assumptions about whether there are differences in long-

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Figure 2. Relationship between relative reduction in mortality and the cost-effectiveness of helicopter EMS. *A*, 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. *B*, Effect of overtriage rate on cost-effectiveness of helicopter EMS. According to analysis of national data, 36% of patients transported by helicopter EMS have only minor injuries. The 2 dotted lines demonstrate how the cost-effectiveness of helicopter EMS changes according to the highest and lowest regional overtriage rates observed in national data. *C*, Effect of difference in disability outcomes on cost-effectiveness of helicopter EMS. In our base case, we assume no difference in disability outcomes. The 2 dotted lines demonstrate how the cost-effectiveness of helicopter EMS changes according to whether helicopter EMS is associated with worse or better disability outcomes as measured by the SF-6D quality of life scale during the course of a lifetime. *ICER*, incremental cost-effectiveness ratio.

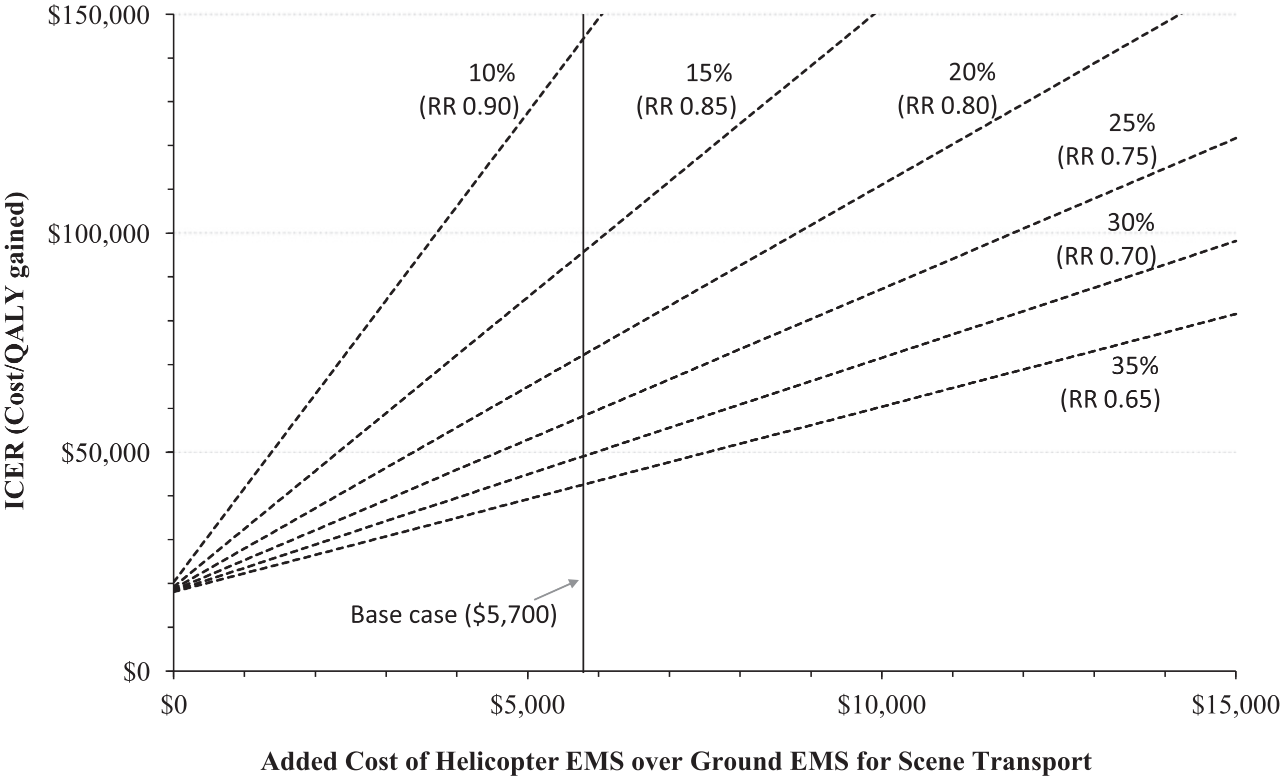

Figure 3. Effect of the variation in the added cost of helicopter EMS on the threshold mortality reduction needed to be cost-effective. According to the Medicare Fee Schedule, we assume that the helicopter EMS costs about $5,700 more than ground EMS transport for patients located 55 miles from a trauma center (our base case assumption). The plotted lines demonstrate how the cost-effectiveness of helicopter EMS would change according to the assumed relative mortality reduction and the regional variation in the added cost of helicopter EMS over ground EMS.

term patient disability outcomes by transport mode (Figure 2*C*). If helicopter EMS enabled a sustained improvement in quality of life by 0.01 on the SF-6D utility scale during the course of a lifetime, helicopter transport would be cost-effective at $77,771 per quality-adjusted life-year. 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 27% reduction in mortality (RR 0.73) to cost less than $100,000 per quality-adjusted life-year.

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 per quality-adjusted life-year 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 it would be for helicopter EMS to have a fatal crash during transport (Figure E3, available online at http://www.annemergmed.com). Table 2 summarizes the relative mortality reduction for patients with serious injuries (Abbreviated Injury Score 3 to 6) needed for helicopter EMS to be cost-effective according to various scenarios and cost-effectiveness thresholds. The table 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 3.3 in the case in which the incremental costs of a helicopter versus ground transport was $15,000.

For helicopter EMS to have a 95% probability of being cost-effective at a $100,000 per quality-adjusted life-year threshold, given the joint uncertainty of all model parameters, a mortality reduction of 26% (RR 0.74; 2.7 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 used data from national data sets and numerous published studies. The results and

Table 2. Summary results of scenario analyses: minimum reduction in mortality among patients with serious injury triaged to helicopter EMS to be cost-effective relative to ground EMS.*

	$100,000 per QALY-Gained Threshold		$50,000 per QALY-Gained Threshold	
Scenario	**RR Ratio for Inhospital Mortality**	**Lives Needed to Be Saved per 100 Transports (AIS 3–6)**	**RR Ratio for Inhospital Mortality**	**Lives Needed to Be Saved per 100 Transports (AIS 3–6)**
Base case analysis	0.85	1.3	0.70	3.3
Overtriage of patients with minor injury (maximum AIS 1–2)				
Base case analysis (36%)	—	—	—	—
Perfect (0%)	0.90	0.8	0.79	2.0
Lowest observed region (8%)	0.89	0.9	0.78	2.1
Highest observed region (69%)	0.74	2.7	0.56	6.5
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)	0.73	2.8	0.54	5.1
Added per-transport cost of helicopter EMS over ground EMS, $				
Base case analysis (5,700)	—	—	—	—
3,000	0.92	0.7	0.82	1.7
7,500	0.82	1.7	0.65	4.1
10,000	0.78	2.1	0.59	5.3
12,500	0.74	2.7	0.53	6.7
15,000	0.70	3.3	0.49	7.9
Distance from trauma center, miles				
Base case analysis (55)	—	—	—	—
25	0.87	1.1	0.73	2.8
85	0.84	1.4	0.68	3.6

—, same results from base case analysis.
*Assumes that there is a range of patients with minor injuries (AIS 1 to 2) also triaged to helicopter transport (base case analysis=36% unless otherwise indicated) and that patients with minor injuries have no difference in outcomes conditional on transport mode.

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 because 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 in which 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. Although our sensitivity analysis assesses how our results would change according to 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 in which ground EMS coverage is nonexistent, fully replacing helicopter EMS coverage would require up to 6 new ground EMS vehicles, resulting in substantially higher costs per ground transport for the same number of patients transported.[58]

Fourth, we did not compare helicopter EMS transport to a trauma center versus ground EMS transport to a local nontrauma center because virtually all the studies on helicopter versus ground EMS have compared only outcomes of direct transport to a trauma center. Because direct transport to a trauma center rather than a nontrauma center has been shown to reduce mortality, a significant unstudied benefit of helicopter EMS may be in extending direct access

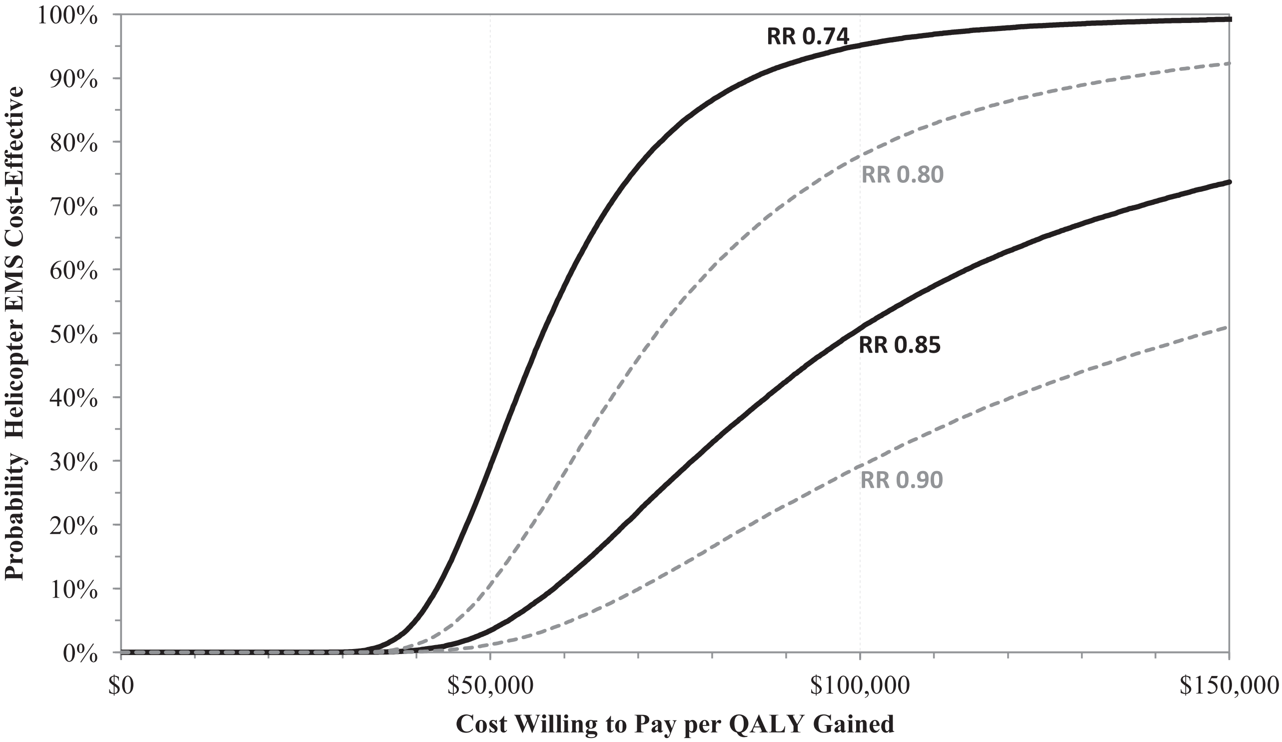

Figure 4. Probabilistic sensitivity analysis of the incremental cost-effectiveness ratio of helicopter EMS versus ground EMS for trauma scene transport according to the size of the relative mortality reduction from helicopter EMS. A threshold mortality reduction of greater than 26% (RR 0.74) is needed for helicopter EMS to be cost-effective in greater than 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 15% (RR 0.85) that was determined with base-case assumptions. The threshold of 15% (RR 0.85) was cost-effective in 51% of simulations if society is willing to pay $100,000 per QALY gained.

to trauma center care when direct transport by ground EMS is not logistically feasible.

DISCUSSION

Compared with ground EMS transport, helicopter scene transport is cost-effective if it results in a reduction in the RR of death for seriously injured trauma patients of at least 15%, given our model assumptions. This translates into the need to save at least 1.3 lives per 100 patients transported with serious injury. Given current uncertainties, helicopter EMS must reduce mortality by more than 26% (2.7 lives per 100 transports with serious injury) to have a 95% probability of being cost-effective at less than $100,000 per quality-adjusted life-year gained. To meet the more conservative threshold of costing less than $50,000 per quality-adjusted life-year gained, helicopter EMS needs to reduce mortality by 30%.

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 during a lifetime horizon, as recommended by the 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. Although some studies of helicopter transport meet this threshold, all are observational and most have major methodological limitations. 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 because 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 observed 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 National Trauma Data Bank, which estimated that helicopter EMS was associated with a 16% increase in the odds of survival (odds ratio 1.16; 95% confidence interval [CI] 1.14 to 1.17), or 1.5 lives saved per 100 patients with severe injury (95% CI 1.4 to

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% versus 57%; $P<.001$) than survivors of ground EMS.[23] These results indicate that 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 that a much higher mortality reduction is needed (27%; Figure 2*C*) for helicopter EMS to be considered cost-effective. The authors also performed a sensitivity analysis excluding ground transports likely not eligible for helicopter transport, according to available data on transport time, and found the estimated survival benefit was cut in half, from 16% to 7% (odds ratio 1.07; 95% CI 1.04 to 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% (hazard ratio 0.67; 95% CI 0.54 to 0.84) for patients with serious injury.[22] Another study of 10,314 patients with moderate to severe head injury (Abbreviated Injury Score >3) with a baseline mortality rate of 23% transported to 5 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 to 2.20) and an adjusted odds ratio for discharge home without services of 1.36 (95% CI 1.18 to 1.58). Although these estimates appear to meet or exceed the risk reductions needed for helicopter EMS cost-effectiveness, both studies are limited by selection bias because they did not exclude the majority of ground EMS transports that were likely ineligible for helicopter EMS because patients were injured too close to the hospital.

Finally, a recent secondary analysis of Resuscitation Outcomes Consortium 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 to 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 United States, 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 effect 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.

To our knowledge, this is also the first cost-effectiveness analysis that takes into account the high proportion of patients who are triaged to helicopter EMS who have only minor injuries. Although a proportion of these patients with minor injury require air medical transport because of logistic and topographic considerations, patients with minor injury 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 according to crash mechanism only, or after routine use of helicopter "auto-launch" at the 911 call instead of after local EMS assessment at the scene, should be further scrutinized because these practices likely lead to overtriage. Our model also implies that 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 because of low flight volume (eg, <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. Because 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 affect cost-effectiveness, except when there is very little clinical benefit from helicopter transport, because the probability of helicopter 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 US EMS systems in which both ground and helicopter transport from the scene of injury are feasible, helicopter EMS must reduce mortality by at least 15% to compare favorably to other health care interventions that are 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 US patients transported to trauma centers. Reducing the overtriage of patients with minor injury to helicopter EMS is a promising avenue for improving its cost-effectiveness. Further rigorous study of the health outcomes of helicopter EMS, including the effect of helicopter transport on long-term disability, is needed to better assess the value of this frequently used, critical care intervention in the United States.

The authors acknowledge Ellen Mackenzie, PhD, Johns Hopkins University, for granting us permission to analyze the primary cost data collected for the National Study on the Cost and Outcomes of Trauma; and Alan Garber, MD, PhD, Harvard University, for his insightful comments and suggestions during the earlier phases of this research.

Supervising editor: Robert A. De Lorenzo, MD, MSM

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Author contributions: MKD and JDG were responsible for study conception and design. MKD and SW were responsible for acquisition of data. MKD, SW, and JDG-F were responsible for statistical analysis. MKD, KLS, NEW, DAS, SW, DKO, and JDG-F were responsible for analysis and interpretation of data. MKD was responsible for drafting the article. KLS, NEW, DAS, SW, DKO, and JDG-F were responsible for critical revision of article for important intellectual content. MKD takes responsibility for the paper as a whole.

Funding and support: By *Annals* policy, all authors are required to disclose any and all commercial, financial, and other relationships in any way related to the subject of this article as per ICMJE conflict of interest guidelines (see www.icmje.org). The authors have stated that no such relationships exist. Dr. Delgado was supported by the Agency for Healthcare Research and Quality (AHRQ) training grant to Stanford University (T32HS00028). Dr. Wang was supported by the National Institutes of Health (NIH)/National Institute of Child Health & Human Development (NICHD) (K23HD051595-02). Dr. Goldhaber-Fiebert was supported in part by an NIH/National Institute on Aging (NIA) Career Development Award (K01AG037593-01A1). Dr. Owens is supported by the Department of Veterans Affairs. This work is the sole responsibility of the authors and does not necessarily represent the official views of the AHRQ or NIH or the Department of Veterans Affairs; these agencies were not involved in the design and conduct of the study; collection, management, and interpretation of data; or the preparation, review, or approval of this article.

Publication dates: Received for publication August 22, 2012. Revisions received December 17, 2012, and February 15, 2013. Accepted for publication February 26, 2013. Corrected online September 3, 2013. See Supplemental Material online at www.annemergmed.com for an explanation of the corrections.

Presented at the Society for Medical Decision Making meeting, October 2010, Toronto, Ontario, CA; and the National Association of EMS Physicians, January 2011, Bonita Springs, FL.

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REFERENCES

1. Centers for Disease Control and Prevention. Web-based Injury Statistics Query and Reporting System (WISQARS) [online]. 2010. National Center for Injury Prevention and Control, Centers for Disease Control and Prevention (producer). Available at: http://www.cdc.gov/ncipc/wisqars. Accessed on September 29, 2010.
2. Finkelstein EA, Corso PS, Miller TR. *Incidence and Economic Burden of Injuries in the United States*. New York, NY: Oxford University Press; 2006.
3. Kirschtein R. Disease-specific estimates of direct and indirect costs of illness and NIH support. Cited January 6, 2010. Available at: http://ospp.od.nih.gov/ecostudies/COIreportweb.htm.
4. MacKenzie EJ, Rivara FP, Jurkovich GJJ, et al. A national evaluation of the effect of trauma-center care on mortality. *N Engl J Med*. 2006;354:366-378.
5. Moylan JA. Impact of helicopters on trauma care and clinical results. *Ann Surg*. 1988;208:673-678.
6. Branas CC, MacKenzie EJ, Williams JC, et al. Access to trauma centers in the United States. *JAMA*. 2005;293:2626-2633.
7. Baxt W, Moody P. The impact of a rotorcraft aeromedical transport emergency care service on trauma mortality. *JAMA*. 1983;249:3047-3051.
8. Moylan JA, Fitzpatrick KT, Beyer A. Factors improving survival in multisystem trauma patients. *Ann Surg*. 1988;207:679-685.
9. Schwartz R, Jacobs L, Juda R. A comparison of ground paramedics and aeromedical treatment of severe blunt trauma patients. *Conn Med*. 1990;54:660-662.
10. Nardi G, Massarutti D, Muzzi R. Impact of emergency medical helicopter service on mortality for trauma in north-east Italy: a regional prospective audit. *Eur J Emerg Med*. 1994;1:69-77.
11. Moront M, Gotschall C, Eichelberger M. Helicopter transport of injured children: system effectiveness and triage criteria. *J Pediatr Surg*. 1996;31:1183-1188.
12. Cunningham P, Rutledge R, Baker CC, et al. A comparison of the association of helicopter and ground ambulance transport with the outcome of injury in trauma patients transported from the scene. *J Trauma*. 1997;43:940-946.
13. Jacobs L, Gabram S, Sztajnkrycer M, et al. Helicopter air medical transport: ten-year outcomes for trauma patients in a New England program. *Conn Med*. 1999;63:677-682.
14. Buntman A, Yeomans K. The effect of air medical transport on survival after trauma in Johannesburg, South Africa. *South Afr Med J*. 2002;92:807-811.
15. Thomas SH, Harrison TH, Buras WR, et al. Helicopter transport and blunt trauma mortality: a multicenter trial. *J Trauma*. 2002;52:136-145.
16. Poste JC, Davis DP, Ochs M, et al. Air medical transport of severely head-injured patients undergoing paramedic rapid sequence intubation. *Air Med J*. 2004;23:36-40.
17. Davis DP, Peay J, Serrano JA, et al. The impact of aeromedical response to patients with moderate to severe traumatic brain injury. *Ann Emerg Med*. 2005;46:115-122.
18. DiBartolomeo S, Sanson G, Nardi G, et al. HEMS vs Ground-BLS care in traumatic cardiac arrest. *Prehosp Emerg Care*. 2005;9:79-84.

19. Brown JB, Stassen NA, Bankey PE, et al. Helicopters and the civilian trauma system: national utilization patterns demonstrate improved outcomes after traumatic injury. *J Trauma*. 2010;69: 1030-1034; discussion 1034−1036.
20. Mitchell AD, Tallon JM, Sealy B. Air versus ground transport of major trauma patients to a tertiary trauma centre: a province-wide comparison using TRISS analysis. *Can J Surg*. 2007;50:129-133.
21. Sullivent EE, Faul M, Wald MM. Reduced mortality in injured adults transported by helicopter emergency medical services. *Prehosp Emerg Care*. 2011;15:295-302.
22. Stewart KE, Cowan LD, Thompson DM, et al. Association of direct helicopter versus ground transport and in–hospital mortality in trauma patients: a propensity score analysis. *Acad Emerg Med*. 2011;18:1208-1216.
23. Galvagno S Jr, Haut E, Zafar S, et al. Association between helicopter vs ground emergency medical services and survival for adults with major trauma *JAMA*. 2012;307:1602-1610.
24. Schiller W, Knox R, Zinnecker H. Effect of helicopter transport of trauma victims on survival in an urban trauma center. *J Trauma*. 1988;28:1127-1134.
25. Nicholl J, Brazier J, Ha S. Effects of London helicopter emergency medical services on survival after trauma. *BMJ*. 1995;311:217-222.
26. Brathwaite C, Rosko M, McDowell R. A critical analysis of on-scene helicopter transport on survival in a statewide trauma system. *J Trauma*. 1998;45:140-146.
27. Chappell V, Mileski W, Wolf S, et al. Impact of discontinuing a hospital-based air ambulance service on trauma patient outcomes. *J Trauma*. 2002;52:486-491.
28. Biewener A, Aschenbrenner U, Rammelt S, et al. Impact of helicopter transport and hospital level on mortality of polytrauma patients. *J Trauma*. 2004;56:94-98.
29. Talving P, Teixeira PG, Barmparas G, et al. Helicopter evacuation of trauma victims in Los Angeles: does it improve survival? *World J Surg*. 2009;33:2469-2476.
30. Bulger EM, Guffey D, Guyette FX, et al. Impact of prehospital mode of transport after severe injury: a multicenter evaluation from the Resuscitation Outcomes Consortium. *J Trauma Acute Care Surg*. 2012;72:567-573.
31. Muelleman RL, Wadman MC, Tran TP, et al. Rural motor vehicle crash risk of death is higher after controlling for injury severity. *J Trauma*. 2007;62:221-225; discussion 225−226.
32. Centers for Medicare & Medicaid Services ambulance fee schedule. Cited November 10, 2011. Available at: www.cms.gov/ambulancefeeschedule/.
33. Bledsoe BE, Wesley AK, Eckstein M, et al. Helicopter scene transport of trauma patients with nonlife-threatening injuries: a meta-analysis. *J Trauma*. 2006;60:1257-1265; discussion 1265−1266.
34. US Government Accountability Office (GAO). *Aviation Safety: Potential Strategies to Address Air Ambulance Safety Concerns*. GAO-09-627T. Washington, D.C. April 22, 2009.
35. Mackenzie EJ, Rivara FP, Jurkovich GJ, et al. The National Study on Costs and Outcomes of Trauma. *J Trauma*. 2007;63:S54-67; discussion S81−86.
36. American College of Surgeons. National Trauma Data Bank. Cited April 4, 2010. Available at: http://www.facs.org/trauma/ntdb/index.html.
37. Eichler HG, Kong SX, Gerth WC, et al. Use of cost-effectiveness analysis in health-care resource allocation decision-making: how are cost-effectiveness thresholds expected to emerge? *Value Health*. 2004;7:518-528.
38. Grosse SD. Assessing cost-effectiveness in healthcare: history of the $50,000 per QALY threshold. *Expert Rev Pharmacoecon Outcomes Res*. 2008;8:165-178.
39. Baker SP, O'Neill B, Haddon W Jr, et al. The Injury Severity Score: a method for describing patients with multiple injuries and evaluating emergency care. *J Trauma*. 1974;14:187-196.
40. Sacco WJ, MacKenzie EJ, Champion HR, et al. Comparison of alternative methods for assessing injury severity based on anatomic descriptors. *J Trauma*. 1999;47:441-446.
41. Weinstein MC, Siegel JE, Gold MR, et al. Recommendations of the Panel on Cost-effectiveness in Health and Medicine. *JAMA*. 1996;276:1253-1258.
42. Diaz MA, Hendey GW, Winters RC. How far is that by air? the derivation of an air:ground coefficient. *J Emerg Med*. 2003;24: 199-202.
43. Blumen I. *A Safety Review and Risk Assessment in Air Medical Transport. Supplement to the Air Medical Physician Handbook*. 2002.
44. National Highway Traffic Safety Administration (NHTSA). NCSA data resource Website, Fatality Analysis Reporting System (FARS) Encyclopedia. Cited November 10, 2009. Available at: http://www-fars.nhtsa.dot.gov/Main/index.aspx.
45. Weir S, Salkever DS, Rivara FP, et al. One-year treatment costs of trauma care in the USA. *Expert Rev Pharmacoecon Outcomes Res*. 2010;10:187-197.
46. Centers for Disease Control and Prevention (CDC). United States life tables, 2005. NVSR Volume 58, Number 10. 132 pp. (PHS) 2010−1120. Available at: http://www.cdc.gov/nchs/products/life_tables.htm. Accessed March 13, 2012.
47. Cameron CM, Purdie SM, Kliewer EV, et al. Long-term mortality following trauma: 10 year follow-up in a population-based sample of injured adults. *J Trauma*. 2005;59:639-646.
48. MacKenzie EJ, Weir S, Rivara FP, et al. The value of trauma center care. *J Trauma*. 2010;69:1-10.
49. Hanmer J, Lawrence WF, Anderson JP, et al. Report of nationally representative values for the noninstitutionalized US adult population for 7 health-related quality-of-life scores. *Med Decis Making*. 2006;26:391-400.
50. Brazier J, Nicholl J, Snooks H. The cost and effectiveness of the London helicopter emergency medical service. *J Health Serv Res Policy*. 2006;1:232-237.
51. Ringburg A, Polinder S, Meulman T, et al. Cost– effectiveness and quality– of–life analysis of physician–staffed helicopter emergency medical services. *Br J Surg*. 2009;96:1365-1370.
52. Hartman M, Catlin A, Lassman D, et al. US health spending by age, selected years through 2004. *Health Aff (Millwood)*. 2008; 27:w1-w12.
53. Centers for Medicare & Medicaid Services (CMS) Office of the Actuary. Health expenditures by age. Cited September 10, 2010. Available at: http://www.cms.gov/Research-Statistics-Data-and-Systems/Statistics-Trends-and-Reports/NationalHealthExpendData/Age-and-Gender-Items/Age2004.html.
54. Cameron CM, Purdie DM, Kliewer EV, et al. Ten-year health service use outcomes in a population-based cohort of 21,000 injured adults: the Manitoba Injury Outcome Study. *Bull World Health Organ*. 2006;84:802-810.
55. Kumaranayake L. The real and the nominal? making inflationary adjustments to cost and other economic data. *Health Policy Plan*. 2000;15:230-234.
56. Briggs A, Sculpher M, Claxton K. *Decision Modelling for Health Economic Evaluation. Dallas, TX: Oxford University Press*; 2006.
57. Thomson DP, Thomas SH. Guidelines for air medical dispatch. *Prehosp Emerg Care*. 2003;7:265-271.
58. Bruhn JD, Williams KA, Aghababian R. True costs of air medical vs ground ambulance systems. *Air Med J*. 1993;12: 262-268.

59. Gearhart PA, Wuerz R, Localio AR. Cost-effectiveness analysis of helicopter EMS for trauma patients. *Ann Emerg Med*. 1997;30:500-506.
60. Rogers FB, Shackford SR, Hoyt DB, et al. Trauma deaths in a mature urban vs rural trauma system: a comparison. *Arch Surg*. 1997;132:376.
61. Delgado MK, Newgard CD, Hsia RY. Helicopter vs ground transportation for patients with trauma. *JAMA*. 2012;308:563-565.
62. Galvagno SM, Baker SP, Haider AH. Helicopter vs ground transportation for patients with trauma—reply. *JAMA*. 2012;308:563-565.
63. Ringburg AN, Thomas AH, Steyerberg EW, et al. Lives saved by helicopter emergency medical services: an overview of literature. *Air Med J*. 2009;28:298-302.
64. Moore L, Lavoie A, Turgeon AF, et al. The trauma risk adjustment model: a new model for evaluating trauma care. *Ann Surg*. 2009;249:1040.
65. Peek-Asa C, Zwerling C, Stallones L. Acute traumatic injuries in rural populations. *Am J Public Health*. 2004;94:1689-1693.
66. Grossman DC, Kim A, Macdonald SC, et al. Urban-rural differences in prehospital care of major trauma. *J Trauma*. 1997;42:723-729.
67. Newgard CD, Zive D, Holmes JF, et al. A multisite assessment of the American College of Surgeons Committee on Trauma field triage decision scheme for identifying seriously injured children and adults. *J Am Coll Surg*. 2011;213:709-721.
68. Carr BG, Caplan JM, Pryor JP, et al. A meta-analysis of prehospital care times for trauma. *Prehosp Emerg Care*. 2006;10:198-206.
69. Medical helicopter prices. FindTheBest.com [retail website]. Available at: http://helicopters.findthebest.com/d/t/Medical. Accessed September 29, 2011.
70. Ground ambulance prices, Arrow Manufacturing, Inc. Available at: http://arrowmfginc.com/new-ambulances/. Accessed September 29, 2011.
71. Thomas SH, Cheema F, Wedel SK, et al. Trauma helicopter emergency medical services transport: annotaed review of selected outcomes-related literature. *Prehosp Emerg Care*. 2002;6:359-371.
72. Thomas SH. Helicopter emergency medical services transport outcomes literature: annotated review of articles published 2000-2003. *Prehosp Emerg Care*. 2003;8:322-333.
73. Thomas SH. Helicopter EMS transport outcomes literature: annotated review of articles published 2004-2006. *Prehosp Emerg Care*. 2007;11:477-488.
74. Brown BS, Pogu KA, Williams E, et al. Helicopter EMS transport outcomes literature: annotated review of articles published 2007-2011. *Emerg Med Int*. 2012;2012:876703.
75. Taylor CB, Stevenson M, Jan S, et al. A systematic review of the costs and benefits of helicopter emergency medical services. *Injury*. 2010;41:10-20.
76. Polinder S, Haagsma J, Belt E, et al. A systematic review of studies measuring health-related quality of life of general injury populations. *BMC Public Health*. 2010;10:783.
77. Davis KL, Joshi AV, Tortella BJ, et al. The direct economic burden of blunt and penetrating trauma in a manage care population. *J Trauma*. 2007;62:622-629.

APPENDIX

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Tables and Figures

Determination of the national "overtriage" rate for helicopter EMS

National estimates on the utilization of helicopter EMS for scene trauma transports have not previously been published. To generate these estimates, we analyzed the 2010 National Trauma Data Bank (NTDB) National Sample (NSP) maintained by the American College of Surgeons. The 2010 NSP consists of 161,086 injury encounters treated in 91 U.S. Level I and II trauma centers. These encounters are weighted to provide national estimates of care provided in the 453 U.S. Level I and II trauma centers in the U.S. We used Stata survey commands (**svy**) to analyze these data, which are presented in eTable 1.

eTable 1. Helicopter EMS transports (age ≥ 18) from the scene of injury to U.S. Level I and II trauma centers in 2010: analysis of the National Trauma Data Bank National Sample

Statistic	Estimate
U.S. Weighted Estimates:	
Number of transports	44,705 (95% CI: 36,815-52,545)
Proportion of all transports with only minor injuries (AIS 1-2) (i.e. "overtriage rate")	**36.4% (95%CI: 34.1-38.7%)**
Distribution of the trauma center proportion of transports with only minor injuries (AIS 1-2) for centers with at least 10 transports per year	
Mean	33.6% (95% CI: 30.8-36.3%)
Minimum	**8%**
25^{th} percentile	25%
Median	33%
75^{th} percentile	42%
Maximum	**69%**

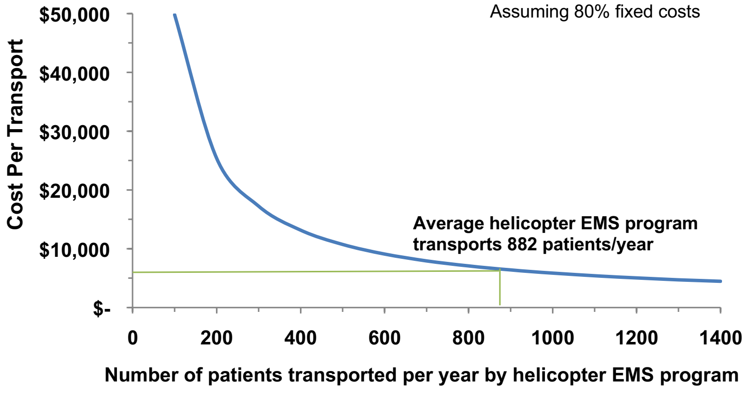
Our analyses show that there were over 44,705 helicopter EMS scene transports to U.S. Level I and II trauma centers in 2010 and that over 16,000 (36%) of these were for patients who had only minor injuries as defined by no injuries with an Abbreviated Injury Scale (AIS) score of 3 or greater.

Estimated EMS costs per transport

For the base case analysis, it was necessary to model the average cost of helicopter and ground EMS scene transport in the U.S. Previous economic analyses of helicopter EMS have reported unit costs of single helicopter EMS programs.[1, 2] These include the annual costs for personnel, capital expenses, operations, administration, insurance, and medical supplies. For example, the annual total operating cost of University of Michigan's Survival Flights HEMS program in fiscal year 1998-99 was $4,761,524. Adjusted for inflation, the total operating costs was $6,103,711 in 2009 dollars. Divided by 1,270 patients transported that year, the average costs/patient flown in 2009 dollars was $4,806.

Based on the data provided from the University of Michigan and Pennsylvania State University HEMS programs, approximately 80% of the operating costs of these programs is fixed (e.g. cost of the aircraft and personnel). Therefore, the cost of transport is heavily dependent on the number of transports per year. To illustrate this, the eFigure 1 below demonstrates the relationship between the number of transports flown per year and costs per transport for a helicopter EMS program assuming similar operating costs as the University of Michigan program.

eFigure 1. Estimated cost (2009 US$) per patient flown by helicopter EMS program volume



The mean number of transports per year for a helicopter EMS program is 882.[3] Based on the assumption that approximately 80% of helicopter EMS costs are fixed, the mean cost per transport across helicopter EMS programs in the U.S. is approximately $6,500. As the number of transports per year decreased below 600, the cost per transport is expected to rise exponentially. However, these estimates are based on just two helicopter EMS programs, and nationally representative operational cost data are currently unavailable.

Therefore, to estimate the average costs of helicopter and ground EMS transport for a given distance we used Medicare reimbursement rates published in the 2010 Medicare Fee Schedule. Medicare reimbursement rates are one of the commonly used data sources in published cost-effectiveness analyses in the U.S.[4] Medicare attempts to set a reimbursement rate based on the value of services needed to provide ambulance services, based on ambulance service level, urban or rural location of transport, loaded mileage, adjusted for geographic practice costs.[5] Private insurance companies often set their reimbursement rates using the Medicare Fee Schedule as a floor, paying approximately 100-140% of what Medicare pays.[6]

For example, the mean fixed base reimbursement rate for helicopter transport in 2010 for patients transported in urban areas was $3,368 and $5,052 in rural areas, prior to adding the mileage rate. In our base case, we assumed an average straight line transport distance of 55 miles based on a previous estimate based on air scene transports in the National Trauma Data Bank.[7] We assumed that most scene transports of patients transported from 55 miles away from a trauma center would be in rural areas, thus we used the rural base rate. The mean rural fixed base rate for a rural advanced life support (ALS) transport was $609. To account for the fact that ground road distances are longer than straight-line air distances, we used a previously published air-ground coefficient of 1.3 (1 air mile = 1.3 ground miles).[8] The assumed costs per transport for our model based on the base rate and loaded mileage rates reimbursed by Medicare are displayed in Figure 3.

eTable 2. Mean 2010 Medicare reimbursement for transport of a patient located 55 miles away from a trauma center in a rural area (base case assumptions for model)

	Base (Fixed) Rate	Mileage Rate	Total Reimbursement
Helicopter			
25 miles	$3,368	$775	$5,828
55 miles	$3,368	$1,777	$6,829
85 miles	$3,368	$2,746	$7,798
Ground (ALS)			
25 miles	$609	$249	$858
55 miles	$609	$519	$1,129
85 miles	$609	$790	$1,400

The reimbursement of $6,800 for a 55-mile helicopter transport from a rural area is remarkably close to the “bottom-up” estimate of $6,500 based on the reported averaged total operating expenses of helicopter EMS programs and the average total number of transports per year by helicopter EMS programs shown in eFigure 1 above. Therefore, we feel using the Medicare Fee Schedule to estimate the national average for the actual cost per transport is a valid approach. Charges for helicopter EMS transport will be much higher depending on the ownership status of the helicopter EMS program (nonprofit vs. investor owned) and the payer mix served by the program. Given that data from the 2010 National Trauma Data Bank indicate that 25% of patients transported by helicopter EMS were uninsured, and another 10% had Medicaid, it is likely that patients with private insurance are charged significantly more than the actual cost per transport to offset unreimbursed costs. In fact charges per transport as high as $25,000 have been reported.[9]

Modeled effect of helicopter EMS on reducing mortality

The effectiveness of helicopter transport compared with ambulance transport is modeled as the differential probability of in-hospital death, the typical outcome in comparative effectiveness studies of EMS transport modes, for patients with serious injuries (AIS 3-6). In the model, the probability of death for patients transported by helicopter EMS with serious injury was pegged to the mean baseline probability of death for patients with serious injury in NSCOT (base case assumption 0.076). The probability of death transported by ground EMS was then set to be equal to the probability of death if transported by helicopter divided by the relative risk (RR) reduction in death from helicopter transport versus ground ambulance transport (range 1.00 indicating no difference to 0.60 indicating at 40% relative difference). To illustrate:

Prob_death_ heli = 0.076 (base case assumption based on NSCOT)

Prob_death_ground = (Prob_death_ heli/RR)

RR = Relative risk reduction in mortality from helicopter EMS vs ground EMS (range 1.00 to 0.60)

So if RR = 0.85, then: Prob_death_ heli = 0.076
Prob_death_ground = 0.076/0.85 = 0.089

Because of the poor quality of the literature defining the relative risk reduction in mortality from helicopter EMS, we assessed differences in costs and outcomes by EMS transport mode over the entire plausible range of the RR (1.00 to 0.60). Also, in order to increase the generalizability of this model, we do not specify the means by which reduced mortality related to transport mode is achieved. In practice this may be due to faster transport time yielding reduced time to definitive care or by improved resuscitation in the field.

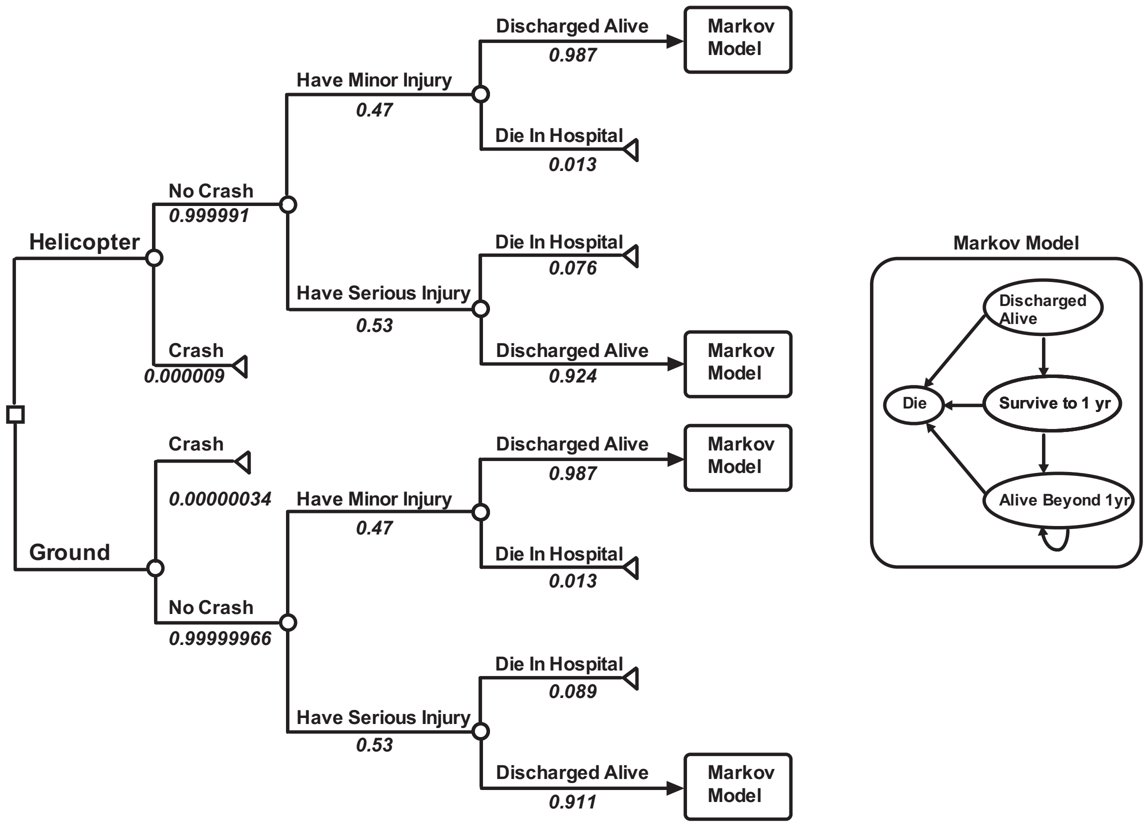
Calculation of quality adjusted life years (QALYs), costs, and the incremental cost effectiveness ratio (ICER)

The model is used to calculate the expected value of quality adjusted life years (QALYs) and costs accrued over the course of a lifetime based on the choice of helicopter versus ground EMS transport and the assumed probabilities and costs reported in Table 1 of the manuscript. This is done by:

1. Multiplying the probabilities across each branch of the tree
2. Adding the costs across each branch of the tree
3. Using a Markov model to project remaining life expectancy and accrued costs after survival to hospital discharge

For illustration, the figure below shows the base case assumed probabilities for each branch point (see Table 1 in the manuscript for more details). In this case, we assume the relative risk reduction in mortality for helicopter EMS compared with ground EMS is 15% (RR 0.85) as demonstrated in the example above, and a regional overtriage rate of 47%.

eFigure 2. Decision tree with branch probabilities shown



For example, if helicopter EMS results in a 15% relative reduction in death for patients with serious injury, the probability that a patient triaged to helicopter transport will be discharged from the hospital alive is:

$$= (0.999991 * 0.47 * 0.987) + (0.999991 * 0.53 * 0.924) = 0.954$$

The probability that patient triaged to the ground transport will be discharged from the hospital alive is:

$$= (0.99999966 * 0.47 * 0.987) + (0.99999966 * 0.53 * 0.911) = 0.947$$

The difference in costs between strategies is driven by two factors:

1) The incremental average cost between transport modes ($6,800 - $1,100 = $5,700);
2) The accrued lifetime health care costs for the additional survivors of patients triaged to helicopter EMS that survive to hospital discharge.

Based on the example above, there are expected to be 7 additional survivors per 1,000 patients triaged to helicopter EMS vs. ground EMS based on the 0.954 probability of survival to discharge for triaged to helicopter EMS and 0.947 probability of survival to discharge from being triage to ground EMS.

To estimate lifetime health care costs, we used observed data collected by the Centers for Medicare and Medicaid Services (CMS) as shown in the table below. We adjusted these data by multiplying the annual health care costs by a factor of 1.45 (hazard ratio for the annual health care costs for patients with serious injuries vs the general population) found in the largest longitudinal cohort study on the costs of trauma victims[10] (see eTable 3 below).

eTable 3: Assumed annual health expenditures among survivors of serious injury

Age	Mean Annual Health Expenditures: General U.S. Population (CMS Office of Actuary)	Estimated Mean Annual Health Expenditures: Among Survivors of Serious Injury
19-44	$3,770	$5,460
45-54	$5,840	$8,470
55-64	$8,730	$12,660
65-74	$12,080	$17,520
75-84	$18,370	$26,640
85 or older	$28,800	$41,760

For example, a 43-year-old man who survives a serious injury and lives until age 73 is expected to accrue $362,300 in health care expenditures. All other factors being equal, we assume no difference in lifetime healthcare costs or survival by transport mode once patients survive to hospital discharge. Therefore, if 1,000 similar 43-year-old patients are triaged to helicopter, and the additional life expectancy is on average 20 years if discharged from the hospital alive, the 7 additional survivors would accrue a total of $1,378,170 in health care costs. So the average additional cost per patient triaged to helicopter transport attributable to increased survival from helicopter transport would be $1,378.

Beyond 1-year post-injury, the conditional probability of remaining alive each year is based on age specific survival probabilities observed by the Centers for Disease Control and reported in U.S. Life Tables.[11] These conditional probabilities are adjusted by a hazard ratio of 5.19, which reflects the higher annual rate of death among trauma victims who survive serious injury relative to the rest of the general population found in large longitudinal cohort study.[12] This hazard ratio is the weighted average of the observed 10-year survival hazard ratios for patients with moderate injury (ISS 9-15) and major injury (ISS >15) based on the distribution of injury severity scores in the NSCOT cohort.[13]

The Markov model is used to project life expectancy in terms of life-years. In order to compare cost-effectiveness of health care interventions that differentially affect mortality and morbidity, accrued life-years are adjusted to take into account quality of life. The convention is to measure patient quality of life, or utility, on a scale of 1 (perfect) to 0 (dead). Based on data from the NSCOT, the mean quality of life on the SF-6D scale at 1-year post serious injury is 0.70.[14] The SF-6D is derived from 11 questions that are part of the SF-36 scale (Version 2). The questionnaire assesses six dimensions of health (physical function, role limitations, social function, pain, mental health, and vitality). Each dimension of health is measured on five levels, which together define 18,000 multiattribute health states. SF-6D utility scores range from 0.30 (least healthy) to 1.00 (full health). Persons who die are assigned a score of 0. A copy of the SF-6D questionnaire is available at: http://thehealthscience.com/wiki/SF-6D.

We assume, as in previous cost-effectiveness studies on trauma, that quality of life after serious injury does not measurably improve after 1-year post trauma.[14] We also assume, that quality of life decreases with age over time.[15] In eFigure 4 below we present our assumptions for the mean quality of life by decade of survival for patients who have a serious injury at age 43 years old, the mean age for trauma patients in the NSCOT cohort.

eTable 4: Assumed quality life among survivors of serious trauma transported by either helicopter or ground EMS

Survival Age	Estimated Mean Quality of Life on SF-6D Scale After Surviving Serious Trauma at Age 43
45	0.6976
55	0.6832
65	0.657
75	0.627
85	0.5978

When calculating lifetime costs and QALYs, a standard discount rate of 3% is applied because costs and outcomes that occur in the future usually have less present value than costs and outcomes realized today.[4] The discount rate formula, where the discount rate is 3% (r=0.03) is:

Present value of costs or QALYs = (Future value at year n) / (1+ r)^n where n=year

The incremental cost-effectiveness ratio (ICER) is calculated from the ratio of the incremental costs divided by the incremental QALYs gained (after discounting):

$$\frac{\text{(Lifetime Costs after Helicopter Transport)} - \text{(Lifetime Costs after Ground Transport)}}{\text{(Lifetime QALYs after Helicopter Transport)} - \text{(Lifetime QALYs after Ground Transport)}}$$

Assuming a 15% relative risk reduction in mortality among patients with serious injury, the model estimates that 0.63 QALY would be gained per 100 patients at a cost to society of $707,074. This translates to an ICER of $113,082 per QALY gained. Cost-effectiveness estimates based on differences in magnitude of the health benefit from helicopter EMS are shown in eTable 5 below. Cost-effectiveness estimates based on differences in the minor injury overtriage rate are shown in eTable 6 below."

eTable 5. Cost-effectiveness of helicopter EMS vs. ground EMS for trauma scene transport by assumed relative reduction in mortality

Alternative	Lifetime Costs	Incremental Costs	Lifetime QALYs	Incremental QALYs	Incremental Cost Effectiveness Ratio
10% Relative Reduction in Mortality (RR 0.90)					
Ground	$207,806	-	10.73527	-	-
Helicopter	$214,601	$6,795	10.78188	0.046614	$145,765
15% Relative Reduction in Mortality (RR 0.85)					
Ground	$207,298	-	10.70626	-	-
Helicopter	$214,601	$7,302	10.78188	0.075623	$96,564
20% Relative Reduction in Mortality (RR 0.80)					
Ground	$206,727	-	10.67362	-	-
Helicopter	$214,601	$7,874	10.78188	0.108258	$72,731
25% Relative Reduction in Mortality (RR 0.75)					
Ground	$206,080	-	10.63664	-	-
Helicopter	$214,601	$8,521	10.78188	0.145244	$58,667
30% Relative Reduction in Mortality (RR 0.70)					
Ground	$205,340	-	10.59437	-	-
Helicopter	$214,601	$9,261	10.78188	0.187514	$49,388
35% Relative Reduction in Mortality (RR 0.65)					
Ground	$204,486	-	10.54559	-	-
Helicopter	$214,601	$10,115	10.78188	0.236288	$42,807
40% Relative Reduction in Mortality (RR 0.60)					
Ground	$203,490	-	10.48869	-	-
Helicopter	$214,601	$11,110	10.78188	0.29319	$37,896
Results of Threshold Analyses					
15% Relative Reduction in Mortality (RR 0.854): threshold determined from base case assumptions for helicopter EMS to cost < $100,000/QALY					
Ground	$207,352	-	10.70931	-	-
Helicopter	$214,601	$7,249	10.78188	0.072569	$99,891
26% Relative Reduction in Mortality (RR 0.74): reduction needed to have ≥ 95% probability of costing <$100,000 per QALY according to probabilistic sensitivity analysis					
Ground	$205,982	-	10.63106	-	-
Helicopter	$214,601	$8,619	10.78188	0.15082	$57,146
30% Relative Reduction in Mortality (RR 0.70): threshold determined from base case assumptions for helicopter EMS to cost < $50,000/QALY					
Ground	$205,340	-	10.59437	-	-
Helicopter	$216,974	$9,260	10.78188	0.184027	$49,388

Note that the as relative reduction in mortality gets bigger (e.g 10% to 20%), more QALYs are gained, but at a higher incremental cost. This higher cost is due to a higher proportion of survivors transported by helicopter EMS who accrue additional health care costs over a lifetime. The greater percentage increase in QALYs over the additional costs leads to more favorable incremental cost effectiveness ratios.

eTable 6. Cost-effectiveness of helicopter EMS vs. ground EMS for trauma scene transport by assumed "overtriage" rate*

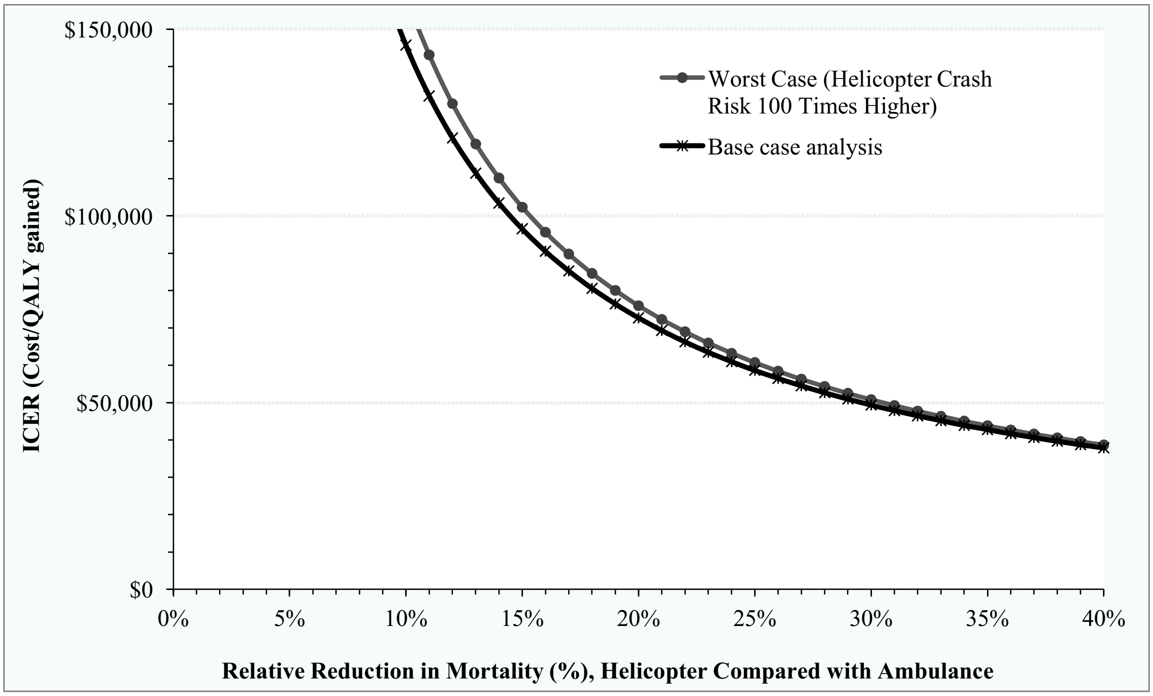
Alternative	Lifetime Costs	Incremental Costs	Lifetime QALYs	Incremental QALYs	Incremental Cost Effectiveness Ratio
70% Overtriage					
Ground	$215,570	-	12.86632	-	-
Helicopter	$222,123	$6,553	12.89908	0.032761	$200,016
60% Overtriage					
Ground	$213,124	-	12.22435	-	-
Helicopter	$219,884	$6,760	12.26896	0.044609	$151,539
50% Overtriage					
Ground	$210,678	-	11.58238	-	-
Helicopter	$217,645	$6,967	11.63884	0.056456	$123,408
40% Overtriage					
Ground	$208,232	-	10.94041	-	-
Helicopter	$215,406	$7,174	11.00872	0.068304	$105,036
30% Overtriage					
Ground	$205,786	-	10.29845	-	-
Helicopter	$213,168	$7,382	10.37860	0.080152	$92,095
20% Overtriage					
Ground	$203,340	-	9.656476	-	-
Helicopter	$210,929	$7,589	9.748476	0.091999	$82,487
10% Overtriage					
Ground	$200,894	-	9.014508	-	-
Helicopter	$208,690	$7,796	9.118355	0.103487	$75,072

"Overtriage rate" = proportion of patients flown with only minor injuries (maximum Abbreviated Injury Scale 1-2). This analysis also assumes helicopter EMS reduces mortality by 15% (RR 0.85), the minimum reduction in mortality needed for helicopter EMS to cost less than $100,000 per QALY gained using base case assumptions.

Sensitivity analyses

In addition to the sensitivity analyses presented in the manuscript, we planned ahead of time to do a two-way sensitivity analysis evaluating the effect of the uncertainty in the difference of estimated crash risks by transport mode and survival benefit from helicopter EMS. As demonstrated in eFigure 3, there is very little difference in the estimates even if the helicopter crash risk is 100 times higher than reported, relative to the crash risk of a commercial light truck (the assumed crash risk of ground ambulance transport for the purposes of this model).

eFigure 3. The effect of the assumed helicopter crash risk probability on the cost effectiveness of helicopter EMS.



ICER: Incremental cost-effectiveness ratio. In the base case scenario, we assume that ground ambulances have the same risk of a fatal crash as a commercial light truck. In the worst case scenario, we assume that the helicopter crash risk is 100 times greater than reported by Blumen et al.[42] For example, if it assumed that helicopter EMS reduces mortality by 15% (RR 0.85), then the impact on cost-effectiveness is minimal. However, as the mortality reduction approaches zero, the impact of the uncertainty of the helicopter crash risk has a greater impact on the cost-effectiveness of helicopter EMS.

Probabilistic sensitivity analysis

While two-way sensitivity analysis is useful in demonstrating the impact of two parameters varying in the model (helicopter EMS relative mortality reduction and overtriage rate), it may be necessary to examine the relationship of three or more different parameters changing simultaneously. However, the presentation and interpretation of multi-way sensitivity analysis becomes increasingly difficult and complex as the number of parameters involved increases.

In most models, each parameter (for example, the probability of a treatment being successful) is assigned a point estimate value. In probabilistic sensitivity analysis, rather than assigning a single value to each parameter, computer software (such as TreeAge) is used to assign a distribution to all parameters in the model. Depending on the specified distribution, the ranges of the distribution are determined by the mean value of the point estimate, the standard deviation, and the 'shape' of the spread of data to support to the point estimate. The spread of distributions correspond to the ranges presented in Table 1. Those ranges are generally the 95% confidence intervals of the parameter found in the literature or from database analysis. Care is taken to ensure that all parameters remain practical. For example, probabilities must always remain between zero and one, while costs can never be negative. The distributions and the parameters to estimate the distributions based on the ranges specified in Table 1 in the manuscript are presented below in eTable 7. All distributions can be recreated in TreeAge Pro by inputting the listed distribution parameters.

eTable 7: Distributions and distribution parameters used for probabilistic sensitivity analysis

Variable	Base-Case Value	Distribution	Distribution Parameters
Probability of having serious injury (AIS 3-6) if transported by helicopter	0.636	Beta	n=166,071; r=105,621
Probability of fatal helicopter crash in 55-mile transport	0.000009	Beta	n=191,255; r=4
Probability of a fatal ambulance crash in 55-mile transport	0.00000034	Beta	n=7,245,983; r=6
Helicopter cost per transport, by distance from trauma center ($)			
25 miles	5,800	Triangular	min=5,357; likeliest=5,828; max=6,831
55 miles (base case)	6,800	Triangular	min=6,359; likeliest=6,829; max=7,832
85 miles	7,800	Triangular	min=7,328; likeliest=7,798 max=8,801
ALS ground ambulance cost per transport by distance trauma center, adjusted for longer road distance ($)			
25 miles	900	Triangular	min=779; likeliest=858; max=1,026
55 miles (base case)	1,100	Triangular	min=1,050; likeliest=1,129; max=1,297
85 miles	1,400	Triangular	min=1,321; likeliest=1,400 max=1,568
Clinical Assumptions			
Serious Injury Subgroup			
Mean baseline probability of in-hospital death	0.076	Beta	n=5,043; r=383
Mean probability of dying in 1 year, conditional on being discharged alive	0.030	Beta	n=5,043; r=153
1-year mean utility difference between helicopter vs. ground ambulance survivors	0	Normal	mean=0; SD=0.005
Mean mortality hazard ratio for decreased lifetime survival	5.19	Lognormal	u (mean of logs) = ln (5.166081) sigma (SD of logs)= sqrt(ln(5.19/5.166081)*2)
Minor Injury Subgroup			
Mean baseline probability of in-hospital death	0.013	Beta	n=166,071; r=2,159
Mean probability of dying in 1 year, conditional on being discharged alive	0.013	Beta	n=166,071; r=2,159
1-yr mean utility difference between helicopter vs. ground ambulance survivors	0	Normal	mean=0; SD=0.005
Mean mortality hazard ratio for decreased lifetime survival	1.38	Lognormal	u (mean of logs) = ln (1.377687) sigma (SD of logs)= sqrt(ln(1.38/1.377687)*2)
Cost Assumptions			
Serious Injury Subgroup			
Cohort mean cost of hospitalization if discharged alive ($)	59,200	Gamma	alpha=619.917021 lambda=0.010472387
Cohort mean cost of hospitalization if die in hospital ($)	50,700	Gamma	alpha=346.23731096; lambda=0.006824945
Cohort mean 1-yr treatment costs following discharge from index hospitalization ($)	35,400	Gamma	alpha=779.1243982; lambda=0.021980746
Hazard ratio for increased lifetime health care expenditures after major trauma	1.45	Lognormal	u (mean of logs) = ln (1.449690) sigma (SD of logs)= sqrt(ln(1.45/1.449690)*2)

Variable (*cont.*)	Base-Case Value	Distribution	Distribution Parameters
Minor Injury Subgroup			
Cohort mean cost of hospitalization ($); includes ED care for ED discharges	12,900	Gamma	alpha=745.6772342; lambda=0.057772343
Cohort mean 1-yr treatment costs following discharge from index hospitalization ($)	9,300	Gamma	alpha=384.4645279; lambda=0.041483241
Hazard ratio for increased lifetime health care expenditures after major trauma	1.25	Lognormal	u (mean of logs) = ln (1.249960) sigma (SD of logs)= sqrt(ln(1.25/1.249960)*2)

AIS: Abbreviated Injury Scale; 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; SD: standard deviation; sqrt: square root.

To generate Figure 4 in the manuscript, we performed 100,000 runs of the model, each time randomly sampling all the model inputs from the distributions specified in eTable 7. We plotted the proportion of the 100,000 ICERs generated from 100,000 model runs at each assumed relative reduction in mortality (e.g. 15%, RR 0.85) that are less than the willingness to pay threshold ranging from $1 per QALY to $150,000 per QALY. This type of figure is known as a cost-effectiveness acceptability curve (CEAC) and is a common way for summarizing the results of probabilistic sensitivity analyses.

We then identified the threshold mortality reduction by helicopter EMS needed to cost less than $100,000 per QALY in $\geq$ 95% of trial runs. This is akin to identifying the effect size of an intervention for which the 95% confidence interval of that effect size does not cross the null hypothesis (e.g. odds ratio of 1.0 or no difference in outcomes) assuming a certain size study population.

References

1) Gearhart PA, Wuerz R, Localio AR. Cost-effectiveness analysis of helicopter EMS for trauma patients. *Ann Emerg Med*. 1997;30: 500-506.
2) Silbergleit R, Scott PA, Lowell MJ. Cost-effectiveness of helicopter transport of stroke patients for thrombolysis. *Acad Emerg Med*. 2003;10: 966-972.
3) Blumen I. A safety review and risk assessment in air medical transport. Supplement to the Air Medical Physician Handbook. November 2002.
4) Weinstein MC, Siegel JE, Gold MR, et al. Recommendations of the Panel on Cost-effectiveness in Health and Medicine. *JAMA.* 1996;276: 1253-1258.
5) Medicare Advisory Payment Commission. Ambulance Services Payment System; cited [2012 Nov 21]. Available at: http://www.medpac.gov/documents/MedPAC_Payment_Basics_12_ambulance.pdf.
6) Igor Volsky. How Are Medicare Rates Established? Cited [2012 Nov 21]. Available at: http://thinkprogress.org/health/2009/08/13/170906/robertz-medicare/.
7) Brown JB, Stassen NA, Bankey PE, et al. Helicopters and the civilian trauma system: national utilization patterns demonstrate improved outcomes after traumatic injury. *J Trauma*. 2010;69: 1030-1034; discussion 1034-1036.
8) Diaz MA, Hendey GW, Winters RC. How far is that by air? The derivation of an air: ground coefficient. *J Emerg Med*. 2003;24: 199-202.
9) J Aleccia. Air ambulance leave some with sky-high bills: Costs range from $12,000 to $25,000 a flight - and insurance may not pay. *NBCNewscom;* cited [2012 Nov 21]. http://wwwmsnbcmsncom/id/34419018/ns/health-health_care/t/air-ambulances-leave-some-sky-high-bills/ - UMjnirRgq4R.
10) Cameron CM, Purdie DM, Kliewer EV, et al. Ten-year health service use outcomes in a population-based cohort of 21,000 injured adults: the Manitoba injury outcome study. *Bull World Health Organ*. 2006;84: 802-810.
11) Centers for Disease Control and Prevention (CDC) United States Life Tables, 2005. NVSR Volume 58, Number 10. 132 pp. (PHS) 2010-1120. Available at: http://www.cdc.gov/nchs/products/life_tables.htm.
12) Cameron CM, Purdie SM, Kliewer EV, et al. Long-term mortality following trauma: 10 year follow-up in a population-based sample of injured adults. *J Trauma*. 2005;59: 639-646.
13) MacKenzie EJ, Rivara FP, Jurkovich GJ J, et al. A national evaluation of the effect of trauma-center care on mortality. *N Engl J Med*. 2006;354: 366-378.
14) MacKenzie EJ, Weir S., Rivara, FP, et al. The value of trauma center care. *J Trauma*. 2010;69: 1-10.
15) Hanmer J, Lawrence WF, Anderson JP, et al. Report of nationally representative values for the noninstitutionalized US adult population for 7 health-related quality-of-life scores. *Med Decis Making*. 2006;26: 391-400.