Cost-effectiveness of Automated External Defibrillators on Airlines

Peter W. Groeneveld, MD
Jeanne L. Kwong, MBA
Yueyi Liu, MS
Adam J. Rodriguez, MBA
Michael P. Jones, MBA
Gillian D. Sanders, PhD
Alan M. Garber, MD, PhD

Context Installation of automated external defibrillators (AEDs) on passenger aircraft has been shown to improve survival of cardiac arrest in that setting, but the cost-effectiveness of such measures has not been proven.

Objective To examine the costs and effectiveness of several different options for AED deployment in the US commercial air transportation system.

Design, Setting, and Subjects Decision and cost-effectiveness analysis of a strategy of full deployment on all aircraft as well as several strategies of partial deployment only on larger aircraft, compared with a baseline strategy of no AEDs on aircraft (but training flight attendants in basic life support) for a hypothetical cohort of persons experiencing cardiac arrest aboard US commercial aircraft. Estimates for costs and outcomes were obtained from the medical literature, the Federal Aviation Administration, the Air Transport Association of America, a population-based cohort of Medicare patients, AED manufacturers, and the Bureau of Labor Statistics.

Main Outcome Measures Quality-adjusted survival after cardiac arrest; costs of AED deployment on aircraft and of medical care for cardiac arrest survivors.

Results Adding AEDs on passenger aircraft with more than 200 passengers would cost $35 300 per quality-adjusted life-year (QALY) gained. Additional AEDs on aircraft with capacities between 100 and 200 persons would cost an additional $40 800 per added QALY compared with deployment on large-capacity aircraft only, and full deployment on all passenger aircraft would cost an additional $94 700 per QALY gained compared with limited deployment on aircraft with capacity greater than 100. Sensitivity analyses indicated that the quality of life, annual mortality rate, and the effectiveness of AEDs in improving survival were the most influential factors in the model. In 85% of Monte Carlo simulations, AED placement on large-capacity aircraft produced cost-effectiveness ratios of less than $50 000 per QALY.

Conclusion The cost-effectiveness of placing AEDs on commercial aircraft compares favorably with the cost-effectiveness of widely accepted medical interventions and health policy regulations, but is critically dependent on the passenger capacity of the aircraft. Placing AEDs on most US commercial aircraft would meet conventional standards of cost-effectiveness.

JAMA. 2001;286:1482-1489 www.jama.com

Out-of-hospital cardiac arrest claims the lives of approximately 275 000 persons each year in the United States.[1,2] Automated external defibrillators (AEDs) improve the low-survival rates from cardiac arrest when operated by trained emergency personnel.[3-9] Recent studies[10,11] have emphasized the effectiveness of AEDs in improving survival when used by trained laypersons in casinos and commercial aircraft, with survival rates substantially higher than those achieved by emergency responders.[12] However, AEDs are costly, in terms of equipment, maintenance, and training, so it is unclear whether they represent an efficient use of health care resources.[13,14] Cost-effectiveness analysis can lend insight into which settings are the most strategic for AED deployment.[15]

Cardiac arrest onboard a passenger aircraft is almost always fatal due to delays in emergency medical care.[16] In the hope of improving survival, various airlines have installed AEDs on aircraft since the early 1990s. Deployment of AEDs on Quantas and American Airlines has demonstrated the ability of flight attendants to resuscitate persons who experienced cardiac arrest aboard aircraft.[11,17,18] Prompted by initial reports of AED effectiveness, the US Congress passed the Aviation Medical Assistance Act (1998), which directed the Federal Aviation Administration (FAA) to consider requiring AEDs on all passenger aircraft.[19] In April 2001, the FAA issued a rule requiring all commercial aircraft with at least 1 flight attendant to carry AEDs by 2004.[20] An FAA cost evaluation projected this regulation would cost the airline industry $300 000 per life saved.[21] Some industry observers have questioned the appropriateness of this regulatory action.[22]

We searched the MEDLINE database (1966-2001) using keywords

Author Affiliations: Center for Primary Care and Outcomes Research (Drs Groeneveld, Sanders, and Garber), Graduate School of Business (Ms Kwong and Mr Rodriguez), and Stanford Biomedical Informatics (Ms Liu), Stanford University, Stanford, Calif; Front Line Strategic Management Consulting, Foster City, Calif (Mr Jones); and Veterans Affairs Palo Alto Health Care System, Palo Alto, Calif (Dr Garber).

Corresponding Author and Reprints: Peter W. Groeneveld, MD, Center for Primary Care and Outcomes Research, 179 Encina Commons, MC 6019, Stanford, CA 94305 (e-mail: petegro@healthpolicy.stanford.edu).

defibrillation, *defibrillator*, *cost*, or *economic*, and found 311 titles, of which 3 were cost-effectiveness analyses of AEDs. Two of these studies, which focused on residential communities,[23,24] may contribute to decision making about AED deployment in municipalities and rural areas but do not apply to the diverse settings for which AEDs are now being considered. The only analysis that addressed deployment in a specialized site was by Foutz and Sayre,[25] who examined AED cost-effectiveness in chronic-care facilities. To our knowledge, we are the first to report a cost-effectiveness analysis of AED deployment on passenger aircraft.

The purpose of our study was to evaluate the cost-effectiveness of AEDs on US passenger aircraft. We designed a model that captured airline industry and health care costs as well as the improved survival and quality-of-life benefits of AEDs, to estimate the cost per quality-adjusted life-year (QALY) gained by widespread AED deployment on commercial aircraft.

METHODS

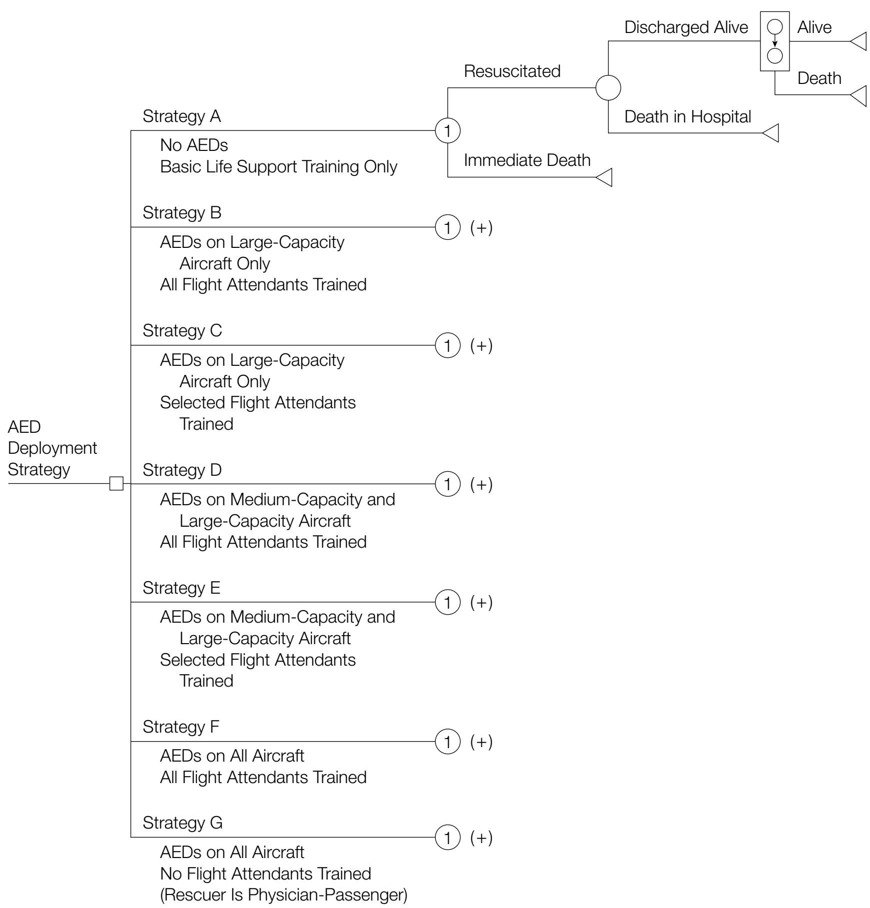
Decision Model

We developed a decision-analytic model to compare several different strategies for AED placement on aircraft. Our model used Markov processes to capture both the immediate costs and benefits of the AED as well as the costs and benefits in the years following cardiac arrest (FIGURE 1). Following the recommendations of the Panel on Cost-effectiveness in Health and Medicine,[26] we took a societal perspective for costs and benefits, discounted at 3% annually. Our study was restricted to costs derived from the US airline industry and health care system. The model was designed to capture all costs and benefits accrued by aircraft cardiac arrest patients until the death of the entire cohort.

Strategies

We hypothesized that placing AEDs on larger aircraft would be more efficient than deployment on smaller aircraft, because larger aircraft carry a disproportionate number of passenger-hours in the US air transportation system.[27] For our base-case, we compared 7 different strategies for AED deployment (TABLE 1). Because most US flight attendants are trained in basic life support (BLS),[21] we assumed that airlines would continue BLS training for flight attendants even if no AEDs were deployed. Thus, for the initial comparison, the lowest cost option A was BLS training for all flight attendants without AED installation. Deployment strategies B and C placed AEDs only on large-capacity (>200 passengers) aircraft. Strategy B assumed that airlines with at least 1 AED-equipped aircraft would train all flight attendants in AED use, while strategy C assumed that airlines could selectively train some flight attendants to use AEDs and designate them to staff AED-equipped aircraft. Strategies D and E had AEDs placed on large-capacity and medium-capacity (>100 passengers) aircraft, while strategy F was full AED deployment on all aircraft with trained flight attendants. Analogous to the training schemes of alternatives B and C, under strategy D all flight attendants would receive AED training, while under strategy E selective training would be used. All flight attendants were trained to operate AEDs in strategy F. As the probability is high of at least 1 health professional onboard any passenger aircraft,[28] strategy G assumed full AED deployment with no flight attendant training and relied on

Figure 1. Decision Model for Automated External Defibrillators (AEDs)



The square node represents the choice of AED deployment strategy. Circles are chance nodes. The plus sign indicates that the subtrees at all chance nodes numbered 1 are the same as for strategy A. A patient who survives to hospital discharge enters a Markov process (represented by the rectangle containing 2 circles and an arrow), which models the possibility of death occurring on an annual basis, and continues until death.

Table 1. Cost-effectiveness Analysis of Automated External Defibrillators (AEDs)*

Strategy	Seating Capacity of Aircraft With AED			Flight Attendants (FAs) With AED Training		Non–AED-Trained FAs With Basic Life Support Training
	>200	100-199	<99	All*	Selective†	
Primary analysis						
A‡						✓
B	✓			✓		✓
C	✓				✓	✓
D	✓	✓		✓		✓
E	✓	✓			✓	✓
F	✓	✓	✓	✓		✓
G§	✓	✓	✓			✓
Additional strategies						
H	✓				✓	
I	✓	✓			✓	
J§	✓	✓	✓			
K‖						

*If an airline had at least 1 aircraft with an installed AED, all flight attendants were trained.
†Only the minimum necessary fraction of an airline's flight attendants trained in AED use.
‡Low-cost strategy.
§Physician-passengers to use AEDs.
‖Alternative low-cost strategy.

physician-passengers to provide treatment in an emergency.

Base-Case Assumptions

Our model followed a hypothetical cohort of patients experiencing cardiac arrest onboard US commercial aircraft during a 12-month period. We assumed aircraft cardiac arrest patients were similar to those in the general population.[2] No published data exist on the actual number of cardiac arrests occurring on aircraft. We therefore based the event rate on 627 956 American Airlines flights in 1997-1999.[11] This represented a 15% sample of US passenger-hours spent aboard aircraft in the year 2001, according to the FAA's estimates for annual growth.[27] The cardiac arrest event rate incorporated both domestic and international flights with US points of origin (TABLE 2). The cost to passengers not experiencing cardiac arrest was captured elsewhere in the model, either by accounting for program costs to the airlines or for medical care costs to society.

Effectiveness

The ability of AEDs to improve survival was estimated from the survival rate measured on American Airlines for 36 cases of cardiac arrest (29 aboard aircraft) treated with AEDs.[11] As the baseline rate of survival in the absence of defibrillators is unknown, we estimated it using the logistic regression model of Valenzuela et al,[29] with predictor values (eg, time to defibrillation) derived from rural emergency medical systems that have transport times longer than 20 minutes.[4,9] The hospital survival rate in the absence of AEDs, assuming a delay in delivery of care, was also abstracted from these rural studies. In our model, AEDs increased both the initial resuscitation rate and the hospital discharge rate after cardiac arrest. Rapid defibrillation can improve hospital survival by preventing the adverse effects of prolonged cessation of circulation that contribute to mortality after initial resuscitation.[12,30,31]

Outcomes

We assumed that cardiac arrest patients who survived to hospital discharge would be in 1 of 3 health categories: cerebral performance category (CPC)-1: able to function at prearrest level; CPC-2: some cognitive or functional difficulties but able to live independently; or CPC-3/CPC-4: severely impaired, requiring institutional care. These outcomes were obtained from the Heartstart Scotland Project,[32] which examined outcomes in 174 survivors of cardiac arrest. The annual mortality of survivors was estimated from the age-adjusted rate observed in 15 152 Medicare patients who had survived to hospital discharge after cardiac arrest or ventricular arrhythmia.[33]

Costs

Airline costs were obtained from the FAA and the Air Transport Association of America. Wages for flight attendants were estimated from Bureau of Labor Statistics data. We assumed that flight attendants would receive BLS and AED instruction following American Heart Association guidelines for duration and frequency of training. Training costs were approximated by calculating the opportunity cost of employee time and airline resources devoted to BLS and AED training.[26] Medical costs were derived from published estimates of hospital and medical expenditures after cardiac arrest and from Medicare reimbursement claims[33] for 15 152 survivors of cardiac arrest or ventricular arrhythmia (J. P. Weiss, written communication, April 4, 2001). Manufacturers of AEDs provided device costs and maintenance estimates in a telephone survey. We used FAA estimations for volume discounts.[21]

Quality of Life

The quality of life for unimpaired (CPC-1) survivors of cardiac arrest was abstracted from published measures of health care utilities (quality weights) derived from the Health Utilities Index Mark-3 questionnaire, administered a mean (SD) of 9.9 (3.5) months after cardiac arrest.[34,35] The utilities for moderate (CPC-2) and severe (CPC-3/CPC-4) impairment after cardiac arrest were estimated from published measurements of similar levels of impairment in stroke survivors.[36]

Analyses

We calculated the base-case incremental cost-effectiveness. One-way sensitivity analyses were performed on all variables over specified ranges (Table 2). Pairs of variables that appeared influential and correlated were selected for 2-way sensitivity analyses. Monte Carlo analyses were performed in which every parameter was varied simultaneously over a specified probability distribution. Costs and time variables were assigned log-normal distributions,[37] probabilities were assigned logistic distributions,[38] and the incidence of cardiac arrest was modeled by the Poisson distribution.[39] Variables without a definitive distributional form were assigned the normal distribution, which was subsequently tested in sensitivity analysis. Ten thousand simulations were performed to approximate confidence intervals for the primary results. Models were created and analyses were performed using DATA 3.5 (TreeAge Software Inc, Williamstown, Mass) and Excel 2000 (Microsoft Inc, Redmond, Wash).

RESULTS

Base-Case Analysis

The benefit of AEDs was proportional to the number of person-years covered by each strategy (TABLE 3). Deploying AEDs on all aircraft (strategy F) would save approximately 33 lives per year (essentially the 17% survival rate found by Page et al[11]). The average survivor would experience 5.1 QALYs at an incremental cost per QALY of $94 700. Limiting AED deployment to larger aircraft (strategy C) would save fewer lives but would cost only $35 300 per QALY gained.

Sensitivity Analyses

One-way sensitivity analyses identified several influential variables (FIGURE 2). Among these variables were AED effectiveness in improving resuscitation and hospital survival. A 2-way sensitivity analysis of these factors indicated that if the AED resuscitation rate were less than 30% (base-case value [BCV] = 36%) and hospital survival were less than 45% (BCV = 46%), extending AED coverage to small-capacity aircraft would improve outcomes at a cost exceeding $100 000 per QALY. Conversely, to have a cost of less than $50 000 per QALY re-

Table 2. Model Variables, Base-Case Values, and Ranges

Variable	Base-Case	Range	Distribution*	Reference
US airline industry				
Passenger-hours per year (millions)	1773	1600-2000	Normal	43, 55
No. of passenger aircraft	5100	4600-5600	Normal	43, 55
Aircraft cardiac arrests per year	200	140-300	Poisson	2, 11
Flight attendants, No.	117 500	105 000-130 000	Normal	21, 43
Automated external defibrillator (AED) initial training, h	3	2-4	Logistic	56-58
AED renewal training per 2 years, h	1	0.5-1.5	Normal	56-58
Probability of an onboard physician-passenger	0.7	0.5-0.85	Logistic	11
Cardiac arrest, %				
Rate of resuscitation, no AED	4	1-10	Logistic	29
Rate of resuscitation with AED	36	21-51	Logistic	11
Rate of hospital discharge, no AED†	20	13-27	Logistic	4, 9, 29, 59
Rate of hospital discharge with AED†	46	30-70	Logistic	11
Outcomes, %				
Mortality, first year after cardiac arrest	17	10-25	Logistic	32, 33
Subsequent annual mortality	12	6-20	Logistic	32, 33
Post–cardiac arrest quality of life (0-1 scale)				
Unimpaired	0.78	0.56-1.0	Logistic	34
Moderately impaired	0.07	0-0.38	Logistic	36
Severely impaired	0	0-0.5	Logistic	36
Costs, $				
AED purchase	3000	2000-4000	Log-normal	Survey of manufacturers
AED maintenance	125	50-300	Log-normal	Survey of manufacturers
Annual AED training program	41 000	20 000-100 000	Log-normal	21
Annual additional fuel per aircraft with AED	62.50	45-80	Log-normal	27
Hourly wage for new trainees	18	13-20	Log-normal	43
Hourly wage for renewal trainees	23	17-30	Log-normal	21, 43
Hospitalization				
Survive to discharge	14 000	10 000-25 000	Log-normal	33, 60
Death	3500	2500-5000	Log-normal	33, 60
Annual medical				
First year	9500	8000-12 500	Log-normal	33
Subsequent years	7000	5500-10 000	Log-normal	33
Average AED lifetime, y	10	5-15	Log-normal	Survey of manufacturers

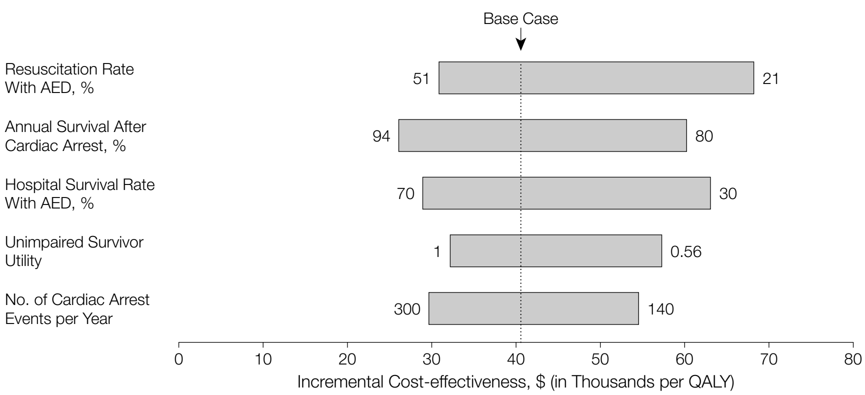
*For use in Monte Carlo simulation.
†Percentage of resuscitated patients eventually discharged from the hospital.

Table 3. Results of Cost-effectiveness Analysis*

Strategy	Description of Strategy	No. of Lives Saved Annually	Average per Patient With Cardiac Arrest† QALY	Average per Patient With Cardiac Arrest† Cost, $	Incremental Cost per QALY, $‡	Simulated 95% Upper Bound, $
A	No AEDs, attendants with BLS training	2	0.04	25 100	Lowest cost reference strategy	NA
B	AEDs on large-capacity aircraft, full training	7	0.18	41 000	Dominated§	NA
C	AEDs on large-capacity aircraft, selective training	7	0.18	30 100	35 300	64 500
D	AEDs on medium- and large-capacity aircraft, full training	31	0.79	55 600	Dominated§	NA
E	AEDs on medium- and large-capacity aircraft, selective training	31	0.79	54 700	40 800	65 200
F	AEDs on all aircraft, full training	33	0.84	59 500	94 700	151 400
G	AEDs on all aircraft, physician-passengers as rescuers	15	0.38	40 700	Dominated∥	NA

*QALY indicates quality-adjusted life-year; AED, automated external defibrillator; BLS, basic life support; and NA, data not applicable.
†Including both surviving patients and those who died.
‡Compared with preceding lower cost strategy.
§More costly than another equally effective strategy.
∥More costly and/or less effective than a combination of other strategies.

Figure 2. One-Way Sensitivity Analyses of the Cost-effectiveness of Automated External Defibrillator (AED) Deployment (Strategy E)



The bars indicate the variability of the cost-effectiveness ratio (x-axis) caused by changes in the value of the indicated variable, all other variables being held constant. Labels on the horizontal bars indicate the range of each 1-way sensitivity analysis. QALY indicates quality-adjusted life-year.

gardless of passenger capacity, AEDs would need to resuscitate 50% of persons experiencing cardiac arrest, with 63% of resuscitated patients surviving to hospital discharge. In comparison, AEDs deployed solely on large-capacity aircraft could resuscitate as few as 25% of patients, with an overall survival rate of only 10%, and still yield a cost of less than $50 000 per QALY. A separate 2-way sensitivity analysis indicated that if utility for an unimpaired survivor were greater than 0.9 (BCV=0.78) and the annual mortality were less than 5% (BCV =12%), the cost-effectiveness of AEDs would be less than $50 000 per QALY for all types of aircraft. The rate of cardiac arrest on aircraft is also critical to cost-effectiveness—if 300 aircraft cardiac arrests occurred annually instead of the baseline estimate of 200, the incremental cost-effectiveness would be reduced to $26 700, $30 100, and $66 000 per QALY for AEDs on large-capacity, medium-capacity, and small-capacity aircraft, respectively.

Monte Carlo Analyses

Monte Carlo simulation is a method by which the uncertainty of a model's input variables can be used to generate confidence intervals for the model's output.[38] Monte Carlo analyses suggested that 95% of simulated cost-effectiveness ratios for AED installation on large-capacity aircraft would be between $11 400 and $74 800 per QALY. Only 14.9% of simulations had incremental cost-effectiveness ratios greater than $50 000 per QALY. The interval for extending deployment to medium-capacity aircraft was $23 000 to $72 100, with 22.3% of the simulations having cost-effectiveness ratios greater than $50 000 per QALY. Finally, the 95% confidence interval for further expanding AED coverage to cover all passenger aircraft was $58 300 to $166 500. Most (99.8%) of these trials had values greater than $50 000 per QALY while 44.2% of trials had values in excess of $100 000 per QALY. None of these boundaries was affected by the choice of modeling distribution (<$5000 per QALY difference) for variables with indeterminate functional form.

Alternative Analyses

A factor not included among our original strategies was the potential elimination of BLS training for flight attendants who staff non–AED-equipped aircraft (strategies A, C, and E) or when physician-passengers would be rescuers (strategy G). When this factor was included via new strategies H, I, J, and K (Table 1), we found that strategy J (placing AEDs on aircraft for use by physician-passengers, but training no flight attendants in BLS or defibrillation) became a viable option at a cost of $45 600 per

QALY. The incremental cost-effectiveness for AED deployment on large-capacity and medium-capacity aircraft (with flight attendants trained to perform defibrillation) compared with the physician-passenger strategy was $94 400 per additional QALY. Further expansion of deployment to all aircraft, compared with limiting deployment to large-capacity and medium-capacity aircraft, cost $106 700 per QALY gained. All other strategies were dominated (more costly and less effective) (FIGURE 3). Additionally, a constraint that was not incorporated in our original strategies was the possibility that airlines would be compelled to offer a single training program to all flight attendants regardless of how many aircraft were equipped with defibrillators. When our model was analyzed with all partial-training strategies removed (C, E, H, and I), the cost-effectiveness of AED deployment on medium-capacity and large-capacity aircraft was $40 800 per QALY, and extending deployment to small-capacity aircraft cost $78 600 per QALY. Finally, when cost and outcome data derived from the Antiarrhythmics Versus Implantable Defibrillator (AVID) trial[40,41] were used instead of the community-based Medicare data, the cost-effectiveness of large-capacity aircraft deployment was $52 600 per QALY, extending deployment to medium-capacity aircraft cost $60 300 per QALY, and deployment on small-capacity aircraft cost $135 700 per QALY.

COMMENT

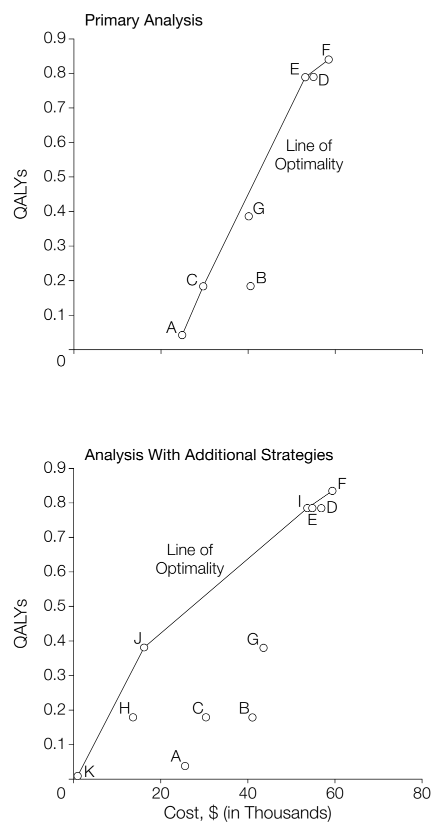
The incremental cost-effectiveness of full AED deployment on commercial aircraft ranges from $35 300 to $94 700 per QALY. The values for deployment on larger aircraft compare favorably with other health care interventions and transportation safety items. For example, a recent study demonstrated that driver-side airbags have a cost-effectiveness of $30 000 per QALY compared with no airbags, and adding passenger-side airbags saves lives at a cost of $76 500 per QALY compared with driver-side airbags alone (values adjusted from published estimates to 2001 dollars).[42]

Key Variables

The cost-effectiveness of AEDs depends on the rate at which they save lives. However, only a few, small studies have assessed the effectiveness of AEDs in specialized settings such as commercial aircraft. In addition to the work of Page et al,[11] O'Rourke et al[18] reported the 5-year experience of Quantas Airlines, in which 2 of 27 patients who experienced cardiac arrest eventually survived to hospital discharge. (The American Airlines study may be more representative of AED efficacy on domestic flights, since some Quantas patients were not recognized to be in cardiac arrest but were assumed to be sleeping during long trans-Pacific flights.) Additionally, little is known about survival rates from cardiac arrest in comparable settings prior to AED deployment. The assumption that most patients experiencing cardiac arrest aboard aircraft would not survive in the absence of AEDs is plausible, but it may not hold in other settings. Two-way sensitivity and Monte Carlo analyses of our model demonstrated that even if our assumption of AED effectiveness were overly optimistic or baseline survival overly pessimistic, the cost-effectiveness of AED deployment on large-capacity and medium-capacity aircraft is still likely to cost less than $50 000 per QALY gained.

The incidence of cardiac arrest on aircraft also plays an important role in AED cost-effectiveness. There is a paucity of data on the true incidence rate of cardiac arrest during flight. The Aviation Medical Assistance Act of 1998 required

Figure 3. Automated External Defibrillators (AEDs) Deployment Strategies



Strategy

A No AEDs
BLS Training Only

B AEDs on Large-Capacity Aircraft Only
All Flight Attendants Trained

C AEDs on Large-Capacity Aircraft Only
Selected Flight Attendants Trained

D AEDs on Medium-Capacity and Large-Capacity Aircraft
All Flight Attendants Trained

E AEDs on Medium-Capacity and Large-Capacity Aircraft
Selected Flight Attendants Trained

F AEDs on All Aircraft
All Flight Attendants Trained

G AEDs on All Aircraft
No Flight Attendants Trained
(Rescuer Is Physician-Passenger)

H AEDs on Large-Capacity Aircraft Only
Selected Flight Attendants Trained
No BLS Training for Other Flight Attendants

I AEDs on Medium-Capacity and Large-Capacity Aircraft Only
Selected Flight Attendants Trained
No BLS Training for Other Flight Attendants

J AEDs on All Aircraft
No Flight Attendants Trained
BLS Training Eliminated
(Rescuer is Physician-Passenger)

K No AEDs on Aircraft
No Flight Attendants Trained
BLS Training Eliminated

The slope of the line of optimality indicates incremental cost-effectiveness. Strategies below and to the right of the line of optimality are dominated (more expensive and/or less effective). QALY indicates quality-adjusted life-year; BLS, basic life support.

major air carriers to report in-flight deaths over a 1-year period (108 deaths were recorded),[19] yet some have speculated that airlines may be reluctant to report deaths.[16] The frequency measured by Page et al[11] was derived from a 1997-1999 sample representing only 15% of US aircraft passenger-hours flown in the year 2001. Our analysis suggests that a higher event rate would improve the cost-effectiveness of AED deployment.

Extensions

If airlines could not limit AED training when only a fraction of aircraft were AED-equipped, deployment on large-capacity aircraft only would become an unacceptable (dominated) strategy. Large-capacity aircraft deployment would also be dominated if airlines were able to eliminate AED and BLS training entirely for flight attendants who would not staff AED-equipped aircraft. Currently most airlines have a single health-and-safety training program for flight attendants.[43] Creating different tiers of training may not be feasible or may introduce additional costs (eg, staffing shortages or pay differentials) that were not incorporated into this model.

Limitations

Our analysis has important limitations in quantifying effectiveness. First, the outcomes of rural emergency services may be an imperfect proxy for cardiac arrest outcomes on non–AED-equipped aircraft. However, we found in sensitivity analysis that varying the baseline resuscitation rate from 1% to 10% had no substantial effect on the results. Second, there is incomplete understanding of quality of life after cardiac arrest. Among the studies of quality of life in cardiac arrest survivors,[30,31,44-48] only 1 reported preference-based measures (utilities).[34] This study may have favored patients who were able to return a survey, and thus may have produced biased estimates. We supplemented these data with utilities derived from patients (stroke survivors) for whom comprehensive data exist on health-related utility with differing degrees of neurological impairment. Further follow-up studies of patients who experienced cardiac arrest on aircraft are needed to better determine whether these patients have better or worse outcomes than cardiac arrest survivors in the general population. Finally, we did not account for the potential benefit that AEDs may provide to the millions of passengers who will not experience a cardiac arrest on an aircraft but who enjoy the intangible benefit of greater security. Nevertheless, this value is likely negligible—a recent passenger survey indicated that the small differences in the flight safety records of major carriers do not influence the choice of airline for the vast majority of US travelers.[49]

We also note limitations in the measurement of costs. We did not account for additional costs of diverting an aircraft in mid flight to transport a person experiencing cardiac arrest to the nearest hospital. It is possible that onboard AEDs may increase as well as decrease the frequency of emergency medical diversions. Additionally, attorney and court costs or savings from increased or decreased litigation were excluded. However, Good Samaritan legislation may protect users of AEDs from legal liability.[50] Finally, the use of Medicare data for costs and outcomes potentially biased the results, as this older population may have higher health costs and worse outcomes.[51] We age-adjusted our mortality rate; the values we obtained were comparable with those observed in the community-based Heartstart Scotland Project.[32] An alternative source of economic and outcomes data is the AVID trial—using these data increases the cost per QALY of all AED deployment options. Nevertheless, this result may also be biased, as the use of expensive medical technologies by cardiac arrest patients in the AVID trial was higher than in the general population.[52]

Implications and Recommendations

This study suggests that widespread deployment of AEDs on commercial aircraft is cost-effective when compared with many other health or safety interventions that are generally acceptable. This assessment of cost-effectiveness is robust, particularly for AED installation on large-capacity aircraft—even simultaneous changes in many of the key parameters do not raise the cost above $50 000 per QALY for AED placement. Conversely, BLS training of flight attendants in the absence of AEDs is not cost-effective. The economic benefit of extending AED deployment to small-capacity aircraft is less certain. Our results suggest that careful monitoring of the costs and effectiveness of AEDs is warranted as these devices are deployed on small-capacity aircraft over the next 3 years. Eventual reevaluation of the economic consequences of current policy compared with other safety-related programs would be appropriate.[53]

Determining optimal device deployment locations and identifying AED training candidates are significant challenges for public access defibrillation programs. Cost will be an essential factor in these decisions due to sizeable device and training expenses as well as the infrequency and unpredictability of cardiac arrests. Policymakers will face multiple decisions regarding AED deployment in diverse settings. The ongoing Public Access Defibrillation Trial may address some of the uncertainties in community deployment.[54] However, other settings have special characteristics that substantially influence the costs and likelihood of survival. Our analysis, while not directly applicable beyond passenger aircraft, can guide the construction of similar economic analyses.

Summary

A program of placing AEDs on large-capacity passenger aircraft readily meets conventional standards of cost-effectiveness. Even deployment on medium-capacity passenger aircraft attains generally accepted levels of cost-effectiveness. The cost-effectiveness of deployment on smaller aircraft is less certain. Careful monitoring of the costs and consequences of total aircraft AED deployment is warranted to ensure efficient use of safety-related resources in the airline industry.

Author Contributions: *Study concept and design:* Groeneveld, Kwong, Liu, Rodriguez, Jones, Sanders, Garber.
Acquisition of data: Groeneveld, Kwong, Liu, Rodriguez, Jones.
Analysis and interpretation of data: Groeneveld, Kwong, Liu, Rodriguez, Jones, Sanders, Garber.
Drafting of the manuscript: Groeneveld, Kwong, Liu, Rodriguez, Jones, Sanders, Garber.
Critical revision of the manuscript for important intellectual content: Groeneveld, Kwong, Liu, Rodriguez, Jones, Sanders, Garber.
Statistical expertise: Groeneveld, Sanders, Garber.
Obtained funding: Garber.
Administrative, technical, or material support: Groeneveld, Kwong, Liu, Rodriguez, Jones.
Study supervision: Groeneveld, Sanders, Garber.
Funding/Support: This research was supported by institutional training grant HS00028-15 from the Agency for Healthcare Research and Quality (Dr Groeneveld) and by the Homer Laughlin Endowment.
Acknowledgment: We thank J. Peter Weiss, MD, MSc, Mark B. McClellan, MD, PhD, MPA, and Mark A. Hlatky, MD, for providing data from their Medicare cohort of cardiac arrest survivors.

REFERENCES

1. Gillum RF. Sudden coronary death in the United States: 1980-1985. *Circulation.* 1989;79:756-765.
2. National Center for Health Statistics. *Health United States 2000.* Hyattsville, Md: Centers for Disease Control and Prevention; 2000.
3. Marenco JP, Wang PJ, Link MS, et al. Improving survival from sudden cardiac arrest. *JAMA.* 2001;285:1193-1200.
4. Vukov LF, White RD, Bachman JW, O'Brien PC. New perspectives on rural EMT defibrillation. *Ann Emerg Med.* 1988;17:318-321.
5. Auble TE, Menegazzi JJ, Paris PM. Effect of out-of-hospital defibrillation by basic life support providers on cardiac arrest mortality: a meta-analysis. *Ann Emerg Med.* 1995;25:642-648.
6. Eisenberg MS, Hallstrom AP, Copass MK, et al. Treatment of ventricular fibrillation. *JAMA.* 1984;251:1723-1726.
7. Weaver WD, Hill D, Fahrenbruch CE, et al. Use of the automatic external defibrillator in the management of out-of-hospital cardiac arrest. *N Engl J Med.* 1988;319:661-666.
8. Kellermann AL, Hackman BB, Somes G, Kreth TK, Nail L, Dobyns P. Impact of first-responder defibrillation in an urban emergency medical services system. *JAMA.* 1993;270:1708-1713.
9. Stults KR, Brown DD, Schug VL, Bean JA. Prehospital defibrillation performed by emergency medical technicians in rural communities. *N Engl J Med.* 1984;310:219-223.
10. Valenzuela TD, Roe DJ, Nichol G, et al. Outcomes of rapid defibrillation by security officers after cardiac arrest in casinos. *N Engl J Med.* 2000;343:1206-1209.
11. Page RL, Joglar JA, Kowal RC, et al. Use of automated external defibrillators by a US airline. *N Engl J Med.* 2000;343:1210-1216.
12. Nichol G, Stiell IG, Laupacis A, Pham B, De Maio VJ, Wells GA. A cumulative meta-analysis of the effectiveness of defibrillator-capable emergency medical services for victims of out-of-hospital cardiac arrest. *Ann Emerg Med.* 1999;34:517-525.
13. Ewy GA, Ornato JP. 31st Bethesda Conference. *J Am Coll Cardiol.* 2000;35:832-846.
14. Zipes DP, Wellens HJ. Sudden cardiac death. *Circulation.* 1998;98:2334-2351.
15. Gratton M, Lindholm DJ, Campbell JP. Public-access defibrillation. *Prehosp Emerg Care.* 1999;3:303-305.
16. Crewdson J. Code blue: survival in the sky. *Chicago Tribune.* June 30, 1996;section 2:1-10.
17. Page RL, Hamdan MH, McKenas DK. Defibrillation aboard a commercial aircraft. *Circulation.* 1998;97:1429-1430.
18. O'Rourke MF, Donaldson E, Geddes JS. An airline cardiac arrest program. *Circulation.* 1997;96:2849-2853.
19. *House Subcommittee on Aviation: Hearing on FAA implementation of the Aviation Medical Assistance Act of 1998,* 106th Cong, 2nd Sess (2000). Available at: http://www.house.gov/transportation/aviation/06-20-00/06-20-00memo.html. Accessed November 15, 2000.
20. Federal Aviation Administration. Emergency medical equipment, 66 *Federal Register* 19028 (2001).
21. Sapp F. *Final Regulatory Evaluation, Final Regulatory Flexibility Determination, Final Unfunded Mandate Assessment, Final Trade Impact Assessment.* Washington, DC: Federal Aviation Administration, Office of Aviation Policy, Plans, and Management Analysis; 2001. Publication FAA-2000-7119-395.
22. Flint P. Uneasy seatmates. Presented at: International Air Transport Association's Aircraft Maintenance '98 Conference and Exhibition; November 3, 1998; Dubai, United Arab Emirates.
23. Nichol G, Hallstrom AP, Ornato JP, et al. Potential cost-effectiveness of public access defibrillation in the United States. *Circulation.* 1998;97:1315-1320.
24. Jermyn BD. Cost-effectiveness analysis of a rural/urban first-responder defibrillation program. *Prehosp Emerg Care.* 2000;4:43-47.
25. Foutz R, Sayre M. Automated external defibrillators in long-term care facilities are cost-effective. *Prehosp Emerg Care.* 2000;4:314-317.
26. Gold MR, Siegel JE, Russell LB, Weinstein MC, eds. *Cost-effectiveness in Health and Medicine.* New York, NY: Oxford University Press; 1996.
27. Hofer S, Berardino F, Smith J, Rubin S. *Economic Values for Evaluation of Federal Aviation Administration Investment and Regulatory Decisions.* Washington, DC: Federal Aviation Administration, Office of Aviation Policy and Plans; 1998. Publication FAA-APO-98-8.
28. Rayman RB, Davis JR. Aviation medicine. *JAMA.* 1994;271:1657-1658.
29. Valenzuela TD, Roe DJ, Cretin S, Spaite DW, Larsen MP. Estimating effectiveness of cardiac arrest interventions. *Circulation.* 1997;96:3308-3313.
30. Berek K, Schinnerl A, Traweger C, et al. The prognostic significance of coma-rating, duration of anoxia and cardiopulmonary resuscitation in out-of-hospital cardiac arrest. *J Neurol.* 1997;244:556-561.
31. Thompson RJ, McCullough PA, Kahn JK, O'Neill WW. Prediction of death and neurologic outcome in the emergency department in out-of-hospital cardiac arrest survivors. *Am J Cardiol.* 1998;81:17-21.
32. Sedgwick ML, Dalziel K, Watson J, et al. Performance of an established system of first responder out-of-hospital defibrillation. *Resuscitation.* 1993;26:75-88.
33. Weiss JP, Saynina O, McClellan MB, Hlatky MA. Outcomes and costs associated with implantable cardioverter defibrillator use in Medicare patients with life-threatening ventricular arrhythmia. *Circulation.* 2000;102:395.
34. Nichol G, Stiell IG, Hebert P, et al. What is the quality of life for survivors of cardiac arrest? *Acad Emerg Med.* 1999;6:95-102.
35. Torrance GW, Furlong W, Feeny D, Boyle M. Multi-attribute preference functions: Health Utilities Index. *Pharmacoeconomics.* 1995;7:503-520.
36. Gage BF, Cardinalli AB, Owens DK. The effect of stroke and stroke prophylaxis with aspirin or warfarin on quality of life. *Arch Intern Med.* 1996;156:1829-1836.
37. Pasta DJ, Taylor JL, Henning JM. Probabilistic sensitivity analysis incorporating the bootstrap. *Med Decis Making.* 1999;19:353-363.
38. Doubilet P, Begg CB, Weinstein MC, et al. Probabilistic sensitivity analysis using Monte Carlo simulation. *Med Decis Making.* 1985;5:157-177.
39. Skogvoll E, Lindqvist BH. Modeling the occurrence of cardiac arrest as a Poisson process. *Ann Emerg Med.* 1999;33:409-417.
40. Owens DK, Sanders GD, Harris RA, et al. Cost-effectiveness of implantable cardioverter defibrillators relative to amiodarone for prevention of sudden cardiac death. *Ann Intern Med.* 1997;126:1-12.
41. Antiarrhythmics versus Implantable Defibrillators (AVID) Investigators. A comparison of antiarrhythmic-drug therapy with implantable defibrillators in patients resuscitated from near-fatal ventricular arrhythmias. *N Engl J Med.* 1997;337:1576-1583.
42. Graham JD, Thompson KM, Goldie SJ, et al. The cost-effectiveness of air bags by seating position. *JAMA.* 1997;278:1418-1425.
43. Bureau of Labor Statistics. *Occupational Outlook Handbook.* Washington, DC: US Dept of Labor, Bureau of Labor Statistics; 2000.
44. de Vos R, de Haes HC, Koster RW, de Haan RJ. Quality of survival after cardiopulmonary resuscitation. *Arch Intern Med.* 1999;159:249-254.
45. Eisenberg MS, Bergner L, Hallstrom A. Survivors of out-of-hospital cardiac arrest: morbidity and long-term survival. *Am J Emerg Med.* 1984;2:189-192.
46. Freeman KD, Isaacs ED, Isaacs SM. Quality of life in survivors one to five years after cardiac arrest. *Acad Emerg Med.* 2001;8:431-432.
47. Graves JR, Herlitz J, Bang A, et al. Survivors of out of hospital cardiac arrest. *Resuscitation.* 1997;35:117-121.
48. Roine RO, Kajaste S, Kaste M. Neuropsychological sequelae of cardiac arrest. *JAMA.* 1993;269:237-242.
49. International Air Transport Association. *Corporate Air Travel Survey 1999.* London, England: International Air Transport Association; 2000.
50. SoRelle R. States set to pass laws limiting liability for lay users of automated external defibrillators. *Circulation.* 1999;99:2606-2607.
51. Pinski SL, Yao Q, Epstein AE, et al. Determinants of outcome in patients with sustained ventricular tachyarrhythmias. *Am Heart J.* 2000;139:804-813.
52. Kim SG, Hallstrom A, Love JC, et al. Comparison of clinical characteristics and frequency of implantable defibrillator use between randomized patients in the Antiarrhythmics vs Implantable Defibrillators (AVID) trial and nonrandomized registry patients. *Am J Cardiol.* 1997;80:454-457.
53. Banta HD, Thacker SB. The case for reassessment of health care technology. *JAMA.* 1990;264:235-240.
54. National Heart, Lung, and Blood Institute. Study launched to test public access defibrillation [press release]. Available at: http://www.nhlbi.nih.gov/new/press/aug22-00.htm. Accessed June 29, 2001.
55. Air Transport Association of America, Inc. Industry Annual Report 2000. Available at: www.air-transport.org/public/2000ap/. Accessed February 20, 2001.
56. Every N, Weaver W. AEDs: Automatic and advisory trans-chest defibrillation. In: Tacker W, ed. *Defibrillation of the Heart ICDs, AEDs, and Manual.* St Louis, Mo: Mosby-Year Book Inc; 1994:182-195.
57. Riegel B. Training nontraditional responders to use automated external defibrillators. *Am J Crit Care.* 1998;7:402-410.
58. Varon J, Sternbach GL, Marik PE, et al. Automatic external defibrillators. *Resuscitation.* 1999;41:219-223.
59. Eisenberg MS, Copass MK, Hallstrom AP, et al. Treatment of out-of-hospital cardiac arrests with rapid defibrillation by emergency medical technicians. *N Engl J Med.* 1980;302:1379-1383.
60. Nichol G, Laupacis A, Stiell IG, et al. Cost-effectiveness analysis of potential improvements to emergency medical services for victims of out-of-hospital cardiac arrest. *Ann Emerg Med.* 1996;27:711-720.