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VALUE IN HEALTH

The Impact of Including Passive Benefits in Cost-Effectiveness Analysis: The Case of Automated External Defibrillators on Commercial Aircraft

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ABSTRACT

Objective: Traditional cost–utility analysis assumes that all benefits from health-related interventions are captured by the quality-adjusted life-years (QALYs) gained by the few individuals whose outcome is improved by the intervention. However, it is possible that many individuals who do not directly benefit from an intervention receive utility, and therefore QALYs, because of the passive benefit (aka sense of security) provided by the existence of the intervention. The objective of this study was to evaluate the impact that varying quantities of passive benefit have on the cost-effectiveness of airline defibrillator programs.

Methods: A decision analytic model with Markov processes was constructed to evaluate the cost-effectiveness of defibrillator deployment on domestic commercial passenger aircraft over 1 year. Airline passengers were assigned small incremental utility gains (.001–.01) during an estimated 3-hour flight to evaluate the impact of passive benefit on overall cost-effectiveness.

Results: In the base case analysis with no allowance for passive benefit, the cost-effectiveness of airline automated external defibrillator deployment was $34,000 per QALY gained. If 1% of all passengers received utility gain of .01, the cost-effectiveness declined to $30,000. Cost-effectiveness was enhanced when the quantity of passive benefit was raised or the percentage of individuals receiving passive benefit increased.

Conclusions: Automated external defibrillator deployment on passenger aircraft is likely to be cost-effective. If a small percentage of airline passengers receive incremental utility gains from passive benefit of automated external defibrillator availability, the impact on overall cost-effectiveness may be substantial. Further research should attempt to clarify the magnitude and percentage of patients who receive passive benefit.

Keywords: automated external defibrillator, cardiac arrest, cost-effectiveness, passive benefit, public access defibrillation.

Introduction

In 1993 the US Public Health Service convened The Panel on Cost-Effectiveness in Health and Medicine to standardize the methodology and reporting of cost-effectiveness studies. Among The Panel's principal recommendations was that all cost-effectiveness analyses report results based on a societal perspective [1–3]. The rationale for this approach had many factors, but was largely dependent upon the panel's judgment that the societal perspective best captured the total costs and total benefits of most health interventions.

According to The Panel [1], by taking the societal perspective, "the analyst considers everyone affected by the intervention, and all health effects and costs that flow from it are counted, regardless of who would experience them." Conducting a cost-effectiveness analysis using the societal perspective generally requires that the researcher include numerous categories of cost in the model including costs of future medical care, costs related to transportation, and costs related to family care-

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giving [4–7]. Likewise, the societal perspective suggests that all relevant benefits, both direct and indirect, should be included in the analysis and are reported in terms of quality-adjusted life-years gained (QALYs). While the precise method of quantifying these benefits may vary (standard gamble, time trade-off, etc.), all techniques for measurement of these benefits are similar in that the entire benefit of the intervention is assumed to have been captured in the QALYs gained by the few individuals who receive the specific intervention [8,9]. There is no allowance for gains in utility that may accrue among individuals who never require the intervention, but instead receive passive benefit. Furthermore, traditional cost-effectiveness analysis makes no allowance for the potential utility gains that "innocent bystanders" may receive when an intervention is used to assist somebody else. Passive benefit may be construed as a valuation of the "sense of security" certain individuals may receive because of the availability or use of a particular health intervention, even if the specific individuals never personally require the use of the intervention. Cost–utility models that assume a truly societal perspective accounting for all costs and all benefits resulting from an intervention should attempt to account for this passive benefit.

The recently published study by Page et al. [10] demonstrating that deployment of automated external defibrillators (AEDs) on passenger aircraft may increase the survival rates for cardiac arrest victims provides the opportunity to assess the potential impact of passive benefit on overall cost-effectiveness. Airline defibrillator deployment offers an important opportunity to study the impact of passive benefit because, while only approximately 240 in-flight cardiac arrests occur annually in the United States, over 440 million passengers fly on domestic airlines annually and therefore are indirectly exposed to AEDs. If only a small fraction of these passengers receive a modest quantity of passive benefit from AED availability, the impact could be substantial. Therefore, we created a decision analytic model to measure the clinical and economic costs and benefits associated with deployment of AEDs on passenger aircraft. We then attempted to estimate the impact of various levels of passive benefit on the overall cost-effectiveness of AED deployment.

Methods

Literature Review

Using Medline, the 1966 to 2002 medical literature was searched using the keywords cardiac arrests, defibrillators, and airline medical events. Model inputs were based on this literature as well as hand searching of relevant journals and contact with established experts in aviation medicine.

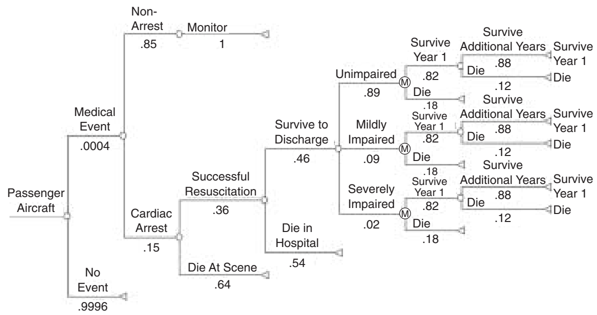

Figure 1 Decision model: Model for strategies 1 and and 2 are identical except for the availability of AEDs and and resulting changes in probabilities of cardiac arrest survival.

Decision Analytic Model

We constructed a decision analytic model (Fig. 1) with Markov processes to estimate the clinical and economic consequences of two management strategies in a cohort of typical airline passengers flying on commercial US aircraft carrying an average of 110 passengers per flight during a 1-year period consisting of 4 million commercial passenger flights: 1) strategy 1—passengers fly on aircraft equipped with standard, FAA-mandated medical kits; 2) strategy 2—passengers fly on aircraft equipped with standard medical kits supplemented by commercially available AED.

We performed the analysis using decision-analytic software (DATA 4.0, Treeage, Wiliamstown, MA). The only difference between the two strategies was the availability of AEDs to the passengers in Strategy 2. Clinical outcomes assessed for each strategy included total survivors of cardiac arrest, life-years gained, and QALYs. All historical costs were adjusted for inflation at 3% per year. Likewise, future costs and benefits were discounted at 3% per annum in accordance with the recommendations of the Panel on Cost-Effectiveness in Health and Medicine [11].

Probability of Clinical Events

The probabilities and ranges of clinical events used in the decision model are shown in Table 1. The baseline probability of a medical event occurring on a specific flight was derived from several recent studies and was estimated to be 1 event per 2500 flights (.0004 events per flight) [10,12,13]. Data from these same studies demonstrated that approx-

Table 1 Clinical probabilities and cost inputs used in model

Variable	Base-case	Sensitivity analysis (ranges)	References
Probability of medical event on given flight	.0004	.0002–.0013	[10,12,13]
Probability that medical event is arrest	.15	.05–.25	[10,12,13]
Probability of successful resuscitation with AED	.36	.20–.40	[10,12,13]
Probability of successful resuscitation without AED	.06	.02–.10	[15–17]
Probability of survival to hospital discharge with AED	.46	.35–.55	[10,13]
Probability of survival to hospital discharge without AED	.30	.10–.50	[15–18]
Probability of surviving arrest unimpaired	.89	.80–1	[30]
Probability of surviving arrest mildly impaired	.09	0–.15	[30]
Probability of surviving arrest severely impaired	.02	0–.05	[30]
Costs ($)			
AED hardware cost (each)	2,500	1,500–3,000	[19]
AED supplies (per use)	150	100–200	[19]
Hospitalization for in-hospital death	3,700	2,650–5,300	[26]
Hospitalization for arrest survivor	46,000	30,000–200,000	[23,25]
Future medical costs for arrest survivor			
First year [26]	10,000	9,300–13,300	[38]
Subsequent years [38]	7,400	5,800–10,600	[38]
Life expectancy			
Mean life expectancy for arrest survivors (years)	6.0	4–8	[27–30]
Utility for arrest survivors (0–1 scale)			
Unimpaired	0.78	0.5–1	[31]
Mildly impaired	0.07	0–.4	[32]
Severely impaired	0	0–.25	[32]

imately 15% of these medical events were actually cardiac arrests [10,12,13].

Strategy 1—no AED on aircraft. For airline passengers who suffer cardiac arrests, all are treated with CPR alone since AEDs are not available. There are no studies specifically reporting the probability of survival after cardiac arrest on passenger aircraft in the absence of AEDs. However, investigations have revealed that a minimum of 20 minutes is required before passengers suffering medical emergencies on aircraft can be evacuated to receive advanced medical care [14]. Therefore, it is reasonable to assume that survival of these patients would approximate survival rates of cardiac arrest victims in other venues with similarly long delays before care is initiated. Data suggest that under these conditions, approximately 6% of cardiac arrest victims would survive to hospital admission [15–17]. Only an estimated 30% of patients who survive to hospital admission (2% of all arrest victims) would be expected to survive to hospital discharge [15–18].

Strategy 2—AED used for all medical events. Under this strategy all passengers suffering medical events receive monitoring with the AED. As in strategy 1, 15% of medical events are cardiac arrests. Based on the results of the studies by Page and O'Rourke [10,13], an estimated 36% of cardiac arrest victims can be expected to survive to hospital admission. Of those patients who are successfully resuscitated, approximately 46% (17% of all cardiac arrest victims) will survive to hospital discharge.

Costs

The cost estimates used in the model are shown in Table 1. The cost of an AED was estimated at $2500 with a useful life of 5 years [19]. Accessing and unpacking the AED results in a $150 restocking charge, regardless of whether a shock is administered [19]. AED training costs were not included in the model because one recent report suggested that the incremental costs of AED training are negligible, while others have suggested that AED training may actually be unnecessary [20–22].

The estimated costs of hospitalization for cardiac arrest survivors have been published in several studies and range from $30,000 to $200,000 [23,24]. Larsen et al. [25] calculated costs of initial hospitalization of either $24,000 or $46,000 depending on whether the patients received implantable cardiac defibrillators or not. We estimated a base case cost of $46,000 by taking the average of the two costs reported by Larsen et al. and adjusting for inflation.

Survivors of cardiac arrests can be expected to accrue substantial medical costs over their remaining lifetime as a result of their cardiac disease. A recent study by Groeneveld et al. [26] reported annual medical costs of cardiac arrest survivors of $10,000 during the first year and $7400 in subsequent years.

Table 2 Annual benefit of AED deployment by strategy, based on an estimated 4 million domestic passenger flights

	Strategy 1—No AED	Strategy 2—AED	Strategy 2—Strategy 1
Medical events	1,600	1,600	—
Cardiac arrests	240	240	—
Survive to hospital discharge	5	40	35
Discounted life-years saved	30	240	210
QALY saved	21	170	149
Incremental cost of AED deployment ($)			5,000,000
Cost per QALY gained ($)			34,000

Life Gained from AED

The benefit of AED deployment stems from any increase in life expectancy among passengers assigned to strategy 2 when compared with those in strategy 1. Mean life expectancies for cardiac arrest survivors in both strategy 1 and strategy 2 were calculated based on data from several studies of long-term survival after cardiac arrest [27–30]. Using these estimates, expected survival after cardiac arrest was estimated to be 6 years.

Quality-of-Life Adjustment

Patients surviving cardiac arrest may have varying degrees of neurologic impairment. The probabilities of various degrees of impairment were based on data from Cobbe et al. [30–32], and utilities were then discounted appropriately.

Passive Benefit

The precise value that airline passengers assign to the passive benefit of AED availability is currently unknown. It is, however, possible to make some reasonable estimates about the percentage of airline passengers who might receive some utility gain from passive benefit of AED availability based on knowledge of the prevalence of cardiovascular disease and associated risk factors. For example, the American Heart Association estimates that 20% of all Americans have cardiovascular disease; more specifically 5% of all Americans have coronary artery disease [33,34]. Similarly, 7% of all Americans are estimated to have diabetes [35].

Given the aging population and prevalence of risk factors for coronary disease, in our base case we estimated that 1% of the 440 million annual airline passengers received a utility gain of .01 during, but not before or after, the estimated 3- hour flight (Table 3).

Sensitivity Analysis

Model inputs. Sensitivity analysis was performed using two different techniques. First, one-way sensitivity analysis was performed for each model input across the entire range of values reported in the literature. We then performed two-way sensitivity analyses for selected inputs that we identified as critical in the one-way analyses.

Passive benefit. Because of the substantial uncertainty regarding both the percentage of airline passengers who may receive a passive benefit and the magnitude of this passive benefit, sensitivity analysis was conducted to assess how variations in these variables would impact the overall cost-effectiveness. The percentage of airline passengers receiving passive benefit was varied from 0.1% to 50% and the utility gain was varied between .001 and .01.

Results

Clinical Outcomes

Based on an estimated 4 million annual commercial passenger flights by domestic carriers, deployment of AEDs on all such flights (strategy 2) could be expected to save an incremental 35 lives annually when compared with no AED (strategy 1) (Table 2). When this survival benefit is converted into quality-adjusted life expectancy, strategy 2 results in an annual net gain of 210 life-years and 149 QALYs when compared with strategy 1.

Cost of AED Deployment

Based on an estimated 4 million annual flights, fully implementing AED programs across all commercial aircraft would be expected to cost an incremental $5.0 million annually: $1.3 million annually for the AED, $240,000 for AED testing and repackaging after each use, $100,000 for in-hospital deaths, $1.6 million for hospitalization of the additional 35 cardiac arrest survivors, and $1.8 million for future medical costs of arrest survivors.

Cost-Effectiveness: Base Case

In the base case analysis, strategy 2 offers improved clinical outcomes (149 QALYs gained) at an increased expense ($5.0 million) when compared

Table 3 Impact of passive benefit on cost-effectiveness

	No passive benefit (base case)	0.1% of passengers receive passive benefit	1% of passengers receive passive benefit	10% of passengers receive passive benefit
Annual number of airline passengers	440,000,000	440,000,000	440,000,000	440,000,000
Number receiving passive benefit	0	440,000	2200,000	4,400,000
Utility benefit	0	0.01	0.01	0.01
QALY gain from AED alone	149	149	149	149
QALY gain from passive benefit	0	1.5	15	150
Total QALY gain from AED	149	150.5	187	299
Incremental cost of AED deployment ($)	5,000,000	5,000,000	5,000,000	5,000,000
Cost per QALY gain ($)	34,000	33,000	30,000	17,000

with strategy 1. These results were used to calculate an incremental cost-effectiveness of $34,000 per QALY gained for strategy 2 when compared with strategy 1.

Cost-Effectiveness: Base Case Including Passive Benefit

Assuming that 1% of all passengers receive an incremental utility gain of .01 during a 3-hour flight, the cost per QALY gained is reduced from $34,000 to $30,000 (Table 3).

Cost-Effectiveness: Sensitivity Analysis

One-way sensitivity analysis. Given the uncertainty in many of the model inputs, multiple one-way sensitivity analyses were performed across the ranges of data available for the model input variables (Table 4). Key variables that substantially impact the results include the probability of cardiac arrest, the relative effectiveness of the AED when compared with CPR alone, the cost of hospitalization for arrest survivors, and the mean life expectancy of unimpaired cardiac arrest survivors.

Two-way sensitivity analysis. Figure 2 demonstrates the impact of varying the probability of in-air cardiac arrest (and thereby the number of arrests) on the incremental cost-effectiveness of the AED program. While the base-case medical event rate (.0004 events per flight) leads to an estimated 240 cardiac arrests annually, published data suggests a range of 120 to as many as 780 annual arrests may occur. Sensitivity analysis demonstrates that the incremental cost per QALY gained associated with an expected 6-year mean life expectancy for an arrest survivor may range from $68,000 (120 annual arrests) to $11,000 (780 annual arrests).

Passive Benefit

Sensitivity analysis examining the relationship between the number of passengers who receive a passive benefit and the magnitude of that passive benefit was also conducted. Table 3 demonstrates that if 10% of all passengers receive a utility gain of .01 during a 3-hour flight, the QALY gain from passive benefit may actually exceed the gain from the direct benefit of AED use. Figure 3 demonstrates the relationship between overall cost-effectiveness of AED deployment, the percentage of patients receiving passive benefit, and the magnitude of the utility gain they receive. Under base case assumptions, as the percentage of passengers receiving an incremental .005 utility gain over a 3-hour flight was increased from 0.1% to 50%, the incremental cost-effectiveness of AED deployment fell from $33,000 per QALY gained to $10,000. Alternatively, under

Table 4 Results from one-way sensitivity analysis across stated ranges

Variable	Range	Cost per QALY gained ($)
Probability of medical event (per flight)	.0002–.0013	79,000–12,000
Probability that medical event is cardiac arrest	.05–.25	119,000–22,000
Probability of surviving arrest to discharge with AED	.10–.30	74,000–21,000
AED purchase costs	1,500–3,000	
($/flight)	.15–.30	35,000–39,000
Hospitalization for cardiac arrest survivors ($)	30,000–200,000	30,000–70,000
Future medical costs for arrest survivors ($)	41,000–71,000	37,000–45,000
Mean life expectancy for survivors	4–8	60,000–30,000

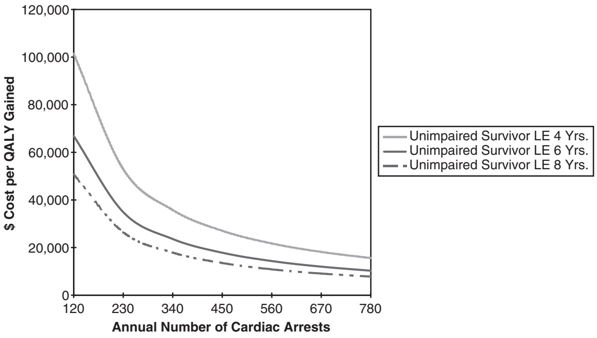

Figure 2 Sensitivity analysis of the effect of increasing the probability of medical events on the incremental cost-effectiveness of airline AEDs. By increasing the probability of medical events across the published range (.0003-.0013 events per flight), the expected number of VF/VT arrests increases as well as shown in the figure. In the base case there are 176 VF/VT arrests annually. LE , life expectancy.

base case assumptions, as the utility gain per passenger was increased from .001 to .01 while holding the percentage of passengers receiving this gain constant at 5%, the cost per QALY gained for AED deployment was reduced from $33,000 to $22,000.

Discussion

The recent report of airline AED deployment resulting in historically high survival rates provides optimism that after decades of frustration, strategic deployment of AEDs may offer an opportunity for reducing out of hospital cardiac arrest mortality rates. Our cost–utility model reported a base case finding of $34,000 per QALY gained supports the findings of Groeneveld et al. [26] that airline AED deployment may be justified on both clinical and economic grounds. If passive benefit is factored into the model, the cost-effectiveness of AED deployment improves even further.

To the best of our knowledge, nobody has attempted to quantify passive benefit or included it in a cost–utility model. However, there is empirical evidence that such a benefit does exist. The FAA, as part of its legislative process, collected public testimony during 1998 to 1999 to measure public interest in airline AED deployment (http://dms.dot.gov/). Among many letters that were submitted, one elderly individual wrote, "seniors who are concerned are reluctant to fly. If they are made aware of in-flight emergency medical care that is available, then they may tend to move about the country more frequently [36]." Similarly, airline industry executives appear to recognize the importance of passive benefit. An article in Northwest Airlines *WorldTraveler* magazine promoting the company's AED deployment began, "What Happens if I get Sick During My Flight [37]?" These two examples tell little about the number of patients who may receive this passive benefit or the quantity of passive benefit they may receive. However, they do support our contention that passive benefit does exist.

Looking beyond airline AED programs, the concept of passive benefit may help to explain other seemingly irrational health-related expenditures. For example, several recent reports have detailed the seemingly irrational behavior of spraying noxious pesticides to kill mosquitoes and limit the spread of West Nile virus. Spending millions of dollars to spray potentially toxic chemicals on densely populated areas in what has, to date, been an unsuccessful attempt to limit the spread of the virus will never make clinical and economic sense in a traditional cost–utility model. However, if the passive benefit that residents receive from the spraying is accounted for, this behavior may appear to be more rational. Passive benefit may also help to explain why the public supports other potentially irrational expenditures including airport security screening or heroic rescues of trapped coal miners.

Our cost-effectiveness model confirms the results of Groeneveld et al. [26] that airline AED deployment can be justified on clinical and economic grounds. The results also suggest that the passive benefit from AED availability to the vast majority of airline passengers who do not experience cardiac arrests may be substantial. Passive benefit should be more precisely quantified to confirm its existence and magnitude. If passive benefit can be shown to exist, future cost–utility analyses that profess a societal perspective should include this important benefit.

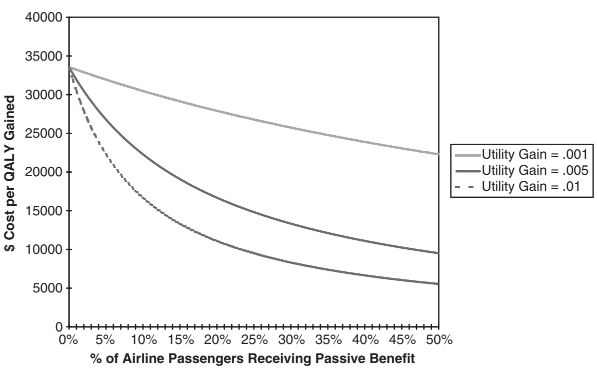

Figure 3 Sensitivity analysis of the effect of increasing passenger utility gained from passive benefit on the incremental cost-effectiveness of airline AEDs.

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