Volume 9 • Number 5 • 2006
VALUE IN HEALTH

Implantable or External Defibrillators for Individuals at Increased Risk of Cardiac Arrest: Where Cost-Effectiveness Hits Fiscal Reality

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ABSTRACT

Objcetives: Implantable cardioverter defibrillators (ICDs) are highly effective at preventing cardiac arrest, but their availability is limited by high cost. Automated external defibrillators (AEDs) are likely to be less effective, but also less expensive. We used decision analysis to evaluate the clinical and economic trade-offs of AEDs, ICDs, and emergency medical services equipped with defibrillators (EMS-D) for reducing cardiac arrest mortality.

Methods: A Markov model was developed to compare the cost-effectiveness of three strategies in adults meeting entry criteria for the MADIT II Trial: strategy 1, individuals experiencing cardiac arrest are treated by EMS-D; strategy 2, individuals experiencing cardiac arrest are treated with an in-home AED; and strategy 3, individuals receive a prophylactic ICD. The model was then used to quantify the aggregate societal benefit of these three strategies under the conditions of a constrained federal budget.

Results: Compared with EMS-D, in-home AEDs produced a gain of 0.05 quality-adjusted life-years (QALYs) at an incremental cost of $5225 ($104,500 per QALY), while ICDs produced a gain of 0.90 QALYs at a cost of $114,660 ($127,400 per QALY). For every $1 million spent on defibrillators, 1.7 additional QALYs are produced by purchasing AEDs (9.6 QALYs/$million) instead of ICDs (7.9 QALYs/$million). Results were most sensitive to defibrillator complication rates and effectiveness, defibrillator cost, and adults' risk of cardiac arrest.

Conclusions: Both AEDs and ICDs reduce cardiac arrest mortality, but AEDs are significantly less expensive and less effective. If financial constraints were to lead to rationing of defibrillators, it might be preferable to provide more people with a less effective and less expensive intervention (in-home AEDs) instead of providing fewer people with a more effective and more costly intervention (ICDs).

Keywords: cost-effectiveness, defibrillators, emergency medical services, heart arrest, rationing.

Background

Health-care payors are increasingly caught in an economic quagmire. On the one hand, they are besieged by patients demanding coverage for new and expensive therapies made available by successful biomedical research [1]. On the other hand, payors are confronted by taxpayers and businesses who are unwilling or unable to contribute ever more money into the insurance pools to pay for these therapies [2–4].

From a cost-effectiveness standpoint, this conundrum is evident in the highly effective and very expensive new therapies that nevertheless have acceptable cost-effectiveness ratios (e.g., $50,000–100,000 per quality-adjusted life-year [QALY] gained). Such new therapies are appealing to the individual patient who is isolated from the true costs of treatment by insurance. For society, however, providing ever larger numbers of expensive, albeit cost-effective therapies to a growing population of patients is contributing to the dramatic increases in health-care expenditures that are currently being observed [5,6]. Nowhere is the impact of this "perfect storm" more apparent than the US Medicare program where these expensive new therapies converge with a growing elderly population to result in unsustainable 10% annual spending growth for the $391 billion program [7].

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10.1111/j.1524-4733.2006.00118.x

  1098-3015/06/292 292–302

The case of implantable cardioverter defibrillators (ICDs) for prevention of cardiac arrest highlights the challenges confronting payors. Early studies with stringent eligibility criteria demonstrated that ICDs reduced cardiac arrest mortality in relatively small populations of patients with severe congestive heart failure (CHF) [8,9]. Subsequent economic evaluations demonstrated that ICDs were also cost-effective for these highly selected patient populations [10]. Because the absolute number of individuals meeting these eligibility criteria was small, the absolute cost to Medicare was limited. Nevertheless, more recent studies have suggested that a far broader spectrum of patients might receive clinical benefit from ICDs [11,12] and economic evaluations have demonstrated ICDs to again be relatively cost-effective in this broader population [13,14]. Medicare administrators have encountered difficulties in that the program may not have sufficient revenue to provide ICDs to the estimated 500,000 Medicare beneficiaries who currently qualify plus the estimated 40,000 new patients each year who might benefit from ICDs without either a substantial increase in funding from the federal government or dramatic reductions in Medicare expenditures in other areas—neither of which are palatable options in the current political environment [15].

Automated external defibrillators (AEDs) deployed in the homes of individuals at high risk for cardiac arrest represent a less expensive, albeit less effective, alternative to ICDs. There are no published studies directly assessing the effectiveness of in-home AEDs and the NIH-funded Home Automatic External Defibrillator Trial will not be complete for some time, but available data from the public access defibrillation (PAD) literature suggest that in-home AEDs are likely to be effective in this setting [16,17]. Traditionally, a less effective therapy (AEDs) would be quickly dismissed in favor of a more effective therapy (ICDs) under the assumption that the goal is to maximize the benefit afforded to the individual. Nevertheless, under the conditions of budgetary constraint as Medicare is now facing, it is possible to envision scenarios whereby society would be better off by providing many individuals with the less expensive therapy (AEDs) rather than by providing fewer patients with the more expensive option (ICDs).

In an effort to clarify these issues, we developed a decision-analytic model to compare the cost-effectiveness of prophylactic ICDs and in-home AEDs with traditional emergency medical services equipped with defibrillators (EMS-D) available in most communities. We then conducted exploratory analyses to examine the clinical and economic trade-offs that might result if policymakers, faced with a fixed national budget for reducing cardiac arrest mortality, focused their efforts on maximizing societal value.

Methods

Literature Review

Medline was used to search the 1966–2004 medical literature using the terms heart arrest, emergency medical services, public access defibrillation, and implantable cardioverter defibrillator as were abstracts of major scientific meetings from 2001–2004. Relevant articles were abstracted by one of the authors (P.C.) to obtain the values for the model. In cases where multiple publications estimating a particular input were available, we used the estimate from the study deemed to be the most methodologically sound. If no single study was superior, we took the mean of the available estimates and used broad confidence intervals in sensitivity analysis.

Decision-Analytic Model

We constructed a Markov decision model by building on our previous analyses assessing the cost-effectiveness of AEDs [18]. The model took the societal perspective to evaluate the lifetime clinical and economic impact of three alternative strategies for preventing cardiac arrest in adults with CHF (Fig. 1): strategy 1–individuals experiencing cardiac arrest are treated by EMS-D (EMS-D strategy); strategy 2—individuals experiencing cardiac arrest at home are initially treated with an in-home AED (AED strategy) followed by EMS-D. Individuals who experience cardiac arrest outside their home do not have access to their AED and receive treatment by EMS-D; strategy 3—all individuals receive a prophylactic ICD to prevent cardiac arrest (ICD strategy). The model was populated with a cohort of Medicare beneficiaries 65 years of age with ischemic cardiomyopathy, ejection fraction less than 30% and meeting entry criteria for the MADIT II Trial [11]. All model inputs are shown in Web Appendix 1.

All historical costs were adjusted from their reported dollar value to 2004 dollars using an inflation rate of 2.5% reflecting the consumer price index inflation rate between 1999 and 2002 [19]. All future costs and benefits were discounted at 3% annually in accordance with the recommendations of the Panel on Cost-effectiveness in Health and Medicine [10]. TreeAgePro decision analysis software (TreeAge Inc., Williamstown, MA) and Excel 2000 (Microsoft Inc., Redmond, WA) were used for all analyses.

Probabilities of Cardiac Arrest and Noncardiac Arrest Mortality

The initial annual mortality for patients assigned to strategies 1 and 2 (11.2%) was derived from data from patients randomized to medical therapy in the MADIT II Trial (Web Appendix 1). This aggregate mortality rate was split into cardiac arrest-related mortality which was assumed to be reduced by in-home AED availability (probability 5.7%) and noncardiac

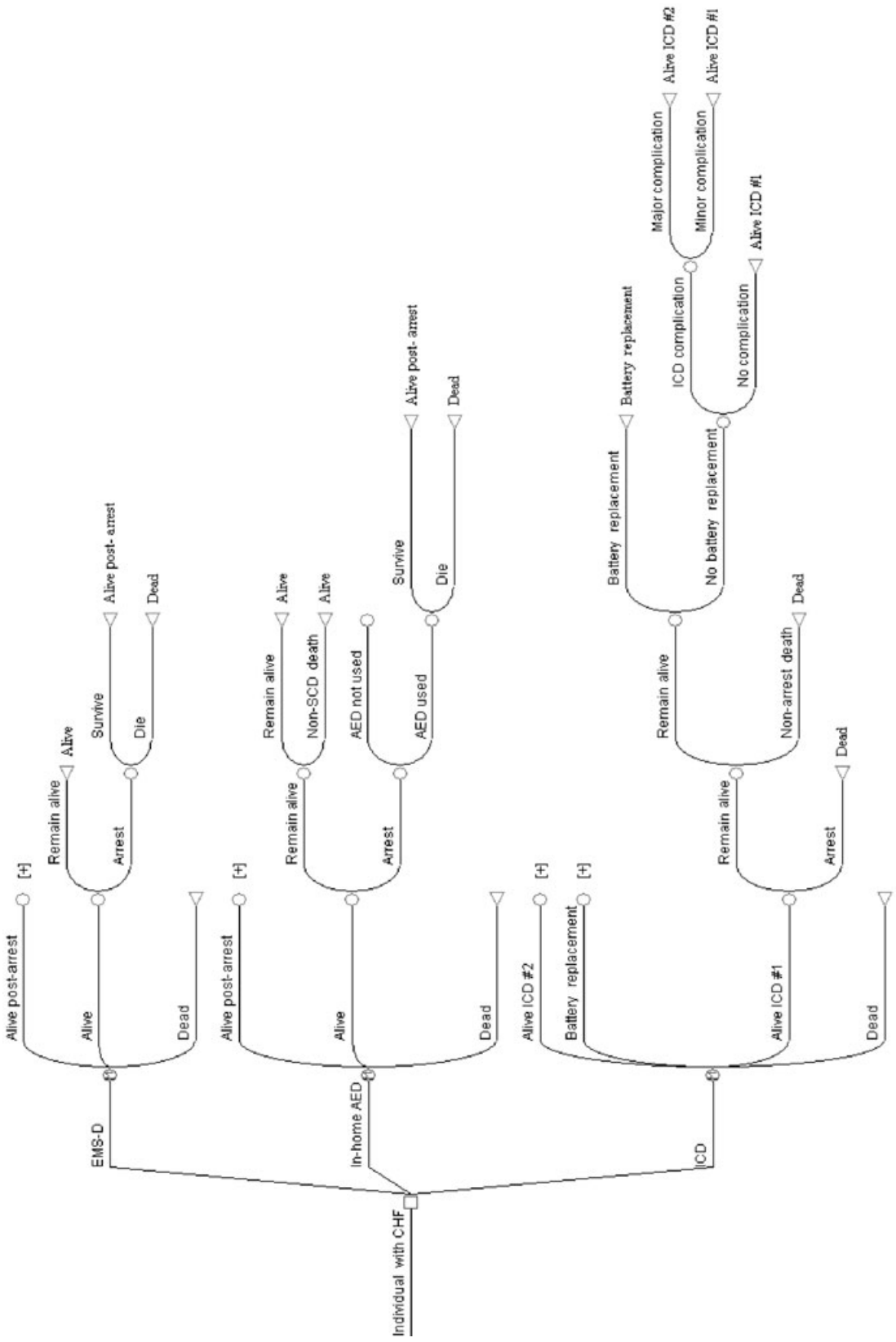

Figure 1 Structure of Markov model. The branches "Alive post-cardiac arrest" actually were subdivided into the three potential neurologic outcomes for cardiac arrest survivors. The sign [+] represents additional branches not displayed. AED, automated external defibrillator; CHF, congestive heart failure; EMS-D, emergency medical services equipped with defibrillator; ICD, implantable cardioverter defibrillator.

arrest-related mortality which was assumed not to be improved by in-home AED availability (probability 5.5%) based on a secondary analysis of the MADIT II Trial [20].

The initial probability of death for individuals assigned to strategy 3 (ICD) was 8.2%; this aggregate mortality was divided into cardiac arrest-related mortality (2.2%) which is significantly reduced by ICDs relative to strategies 1 and 2, and noncardiac arrest-related mortality (6.0%) which increases slightly with ICDs relative to strategies 1 and 2 [20,21]. In subsequent years, overall mortality for all strategies was assumed to increase based on life-table estimates [22].

Probabilities for EMS-D (Strategy 1) and In-Home AED (Strategy 2)

In strategy 1, all individuals suffering cardiac arrest, irrespective of location, were treated by EMS-D. While survival rates to hospital discharge of 25% have been reported with optimized EMS-D, survival rates of 3% to 5% are common in congested urban and remote rural areas [23–29]; this variation reflects the fact that survival falls by approximately 10% per minute delay in defibrillation [30]. In the base-case, 15% of cardiac arrest victims were assumed to survive to hospital discharge based on a time-to-defibrillation interval of approximately 10 minutes [31,32].

In strategy 2, all individuals were given an in-home AED. The benefit of an in-home AED is directly related to any increase in survival that they confer by reducing cardiac arrest mortality. Available evidence suggests that 50% to 70% of out-of-hospital arrests occur at home and that at least 50% are witnessed [33–37]. Even if an arrest occurs at home and is witnessed and an AED is available, it is likely that sometimes the device will not be used. In the base-case, it was assumed that 50% of all arrests occurred at home and that 40% of these arrests were witnessed and treated with the in-home AED. No published studies have examined the impact of in-home AEDs on cardiac arrest survival, but studies examining the impact of PAD on cardiac arrest survival are highly applicable [16,17,38]. Based on these studies and a time-to-defibrillation interval of 5 minutes, cardiac arrest survival with an in-home AED was estimated to be 30% in the base-case [30–32]. We took a conservative view and assumed that an available in-home AED was used exclusively for in-home cardiac arrests and that the only person at risk of suffering an arrest was the individual for whom the AED was prescribed.

Survivors of cardiac arrest in strategies 1 and 2 were assigned to one of the three cerebral performance categories (CPC): CPC-1, unimpaired with no deficit; CPC-2, moderately impaired, but able to live independently; CPC-3/4, severely impaired, requiring institutional care [39–43]. In the base-case, it was assumed that all unimpaired and moderately impaired cardiac arrest survivors received ICDs. Unimpaired survivors with ICDs were assigned an annual mortality rate of 11% reflecting reports of survival of cardiac arrest victims with ICDs [44,45]. Severely impaired survivors had an annual mortality of 30% based on long-term survival of individuals with persistent vegetative states (e.g., stroke, anoxic encephalopathy) [39,46]. We assumed that moderately impaired arrest survivors with ICDs had an annual mortality of 18%, between unimpaired and severely impaired individuals.

Probabilities for ICD (Strategy 3)

The benefit of an ICD (strategy 3) is directly related to any increase in survival that is conferred relative to medical therapy (strategy 1) or an in-home AED (strategy 2). All individuals assigned to strategy 3 received a prophylactic ICD, but had a 0.3% probability of death during implantation [11,21,47,48]. Individuals were at risk of requiring ICD generator replacement each year, based on an estimated battery life of 5 years [49,50], and had a 5% annual risk of developing an ICD-related complication [47,48,51]. These complications were divided into minor complications (e.g., lead malfunctions, need for device reprogramming; 90% of all complications) and major complications (e.g., lead fracture, pocket infection; 10% of all complications), both of which were associated with a small probability of patient death [47,48,51,52]. Individuals who developed their first major complication were assumed to require ICD replacement; a second major complication indicated failure of ICD therapy requiring ICD removal and treatment with amiodarone, which reduced total mortality by 13%, and an in-home AED [53,54].

Costs for EMS-D and In-Home AED (Strategy 1 and Strategy 2)

Individuals assigned to strategies 1 and 2 incurred annual costs of $10,000 for medical treatment of CHF [49,55]. In addition, individuals in strategy 2 were assigned additional costs related to their in-home AED, including the purchase cost of AED, cost of AED maintenance, and cost of AED training (Web Appendix 1).

Costs for ICD (Strategy 3)

Individuals in strategy 3 incurred an initial cost of $50,000 for elective hospitalization for ICD implantation and an annual cost of $10,000 for ongoing medical care [49,51,56,57]. Although a cost of $50,000 for elective ICD implantation is higher than some estimates that have been published previously [13,56,58], this higher value can be accounted for by the fact that it includes the costs of the device, hospitalization for implantation, and professional fees [51]. Costs for ICD generator replacement, minor, and major complications were also included in the model [51,52]. All indi-

viduals who experienced two major complications failed ICD therapy and were assigned costs associated with medical therapy plus an in-home AED.

Costs Related to Cardiac Arrest

Individuals who suffered cardiac arrest and were hospitalized incurred a cost for the hospitalization; this cost varied depending on whether the individual died in the hospital or survived to discharge [49,59–62]. All unimpaired arrest survivors were assigned future costs based on published estimates of the costs of cardiac arrest survivors [59,61]. Severely impaired survivors were assumed to require institutionalization and costs of care were based on costs of individuals who had suffered disabling strokes [63]. As there are no published data on the costs of future care for moderately impaired cardiac arrest survivors, it was assumed that costs were 25% greater than for unimpaired survivors and this assumption was tested through sensitivity analysis.

Utilities

The baseline utility of individuals with CHF was determined to be 0.88 based on a prior study by Tsevat et al. using time trade-off measures to assess utilities in patients with CHF who had survived myocardial infarction [64]. Although numerous studies have assessed the utility of individuals with CHF [64,65], it is unclear whether receipt of ICDs increases or decreases utility [56,57,66]. Based on available data, we assumed that CHF patients with and without ICDs had the same utilities (0.88) and this assumption was evaluated through sensitivity analysis. Disutilities related to ICD implantation, minor and major complications were represented by deducting the number of hospital days required for treatment [51,66,67]. Utility scores for unimpaired cardiac arrest survivors were drawn from published studies [42,68]. Utility scores for the moderately and severely impaired survivors were estimated based on published data from stroke survivors with similar levels of functional impairment [69,70].

Sensitivity Analysis

Because of uncertainty regarding the precise values of many of the model inputs, sensitivity analyses were conducted for each input by allowing each parameter to vary across the range of values identified in the medical literature. Next, two-way sensitivity analyses were conducted using combinations of model variables. Finally, Monte Carlo simulation, which allows all variables to vary simultaneously, was conducted to further assess the robustness of our findings [71]. For this analysis, each input was allowed to vary across the entire range of potential values identified in the literature review (Web Appendix 1); variables related to costs were assigned log-normal distributions, while all others were given normal distributions [72].

Societal Impact of Alternative Distribution Strategies

In the first distribution analysis, a national budget for cardiac arrest prevention in Medicare beneficiaries was established and "capped" at 2002 ICD expenditure levels and model was used to evaluate the clinical and economic trade-offs of each of the three strategies. In the second analysis, the results of the model were "flipped" from the typical "cost per QALY gained" reported in most cost-effectiveness analysis to results based on the QALYs gained per $million spent—an alternative measure of the societal value of available strategies where expenditures are limited to a fixed budget.

Results

Cost-Effectiveness: Base-Case

Providing in-home AEDs to all adults with CHF and an ejection fraction of less than 30% (strategy 2) resulted in a gain of 0.05 QALYs at an incremental cost of $5225 relative to EMS-D alone (strategy 1), resulting in a cost per QALY gained of $104,500 (Table 1). Alternatively, providing all individuals with ICDs (strategy 3) resulted in a gain of 0.90 QALYs at an incremental cost of $114,660 relative to strategy 1, resulting in a cost per QALY gained of $127,400. Providing individuals with ICDs instead of AEDs resulted in a gain of 0.85 QALYs at an incremental cost of $109,435, resulting in an incremental cost-effectiveness ratio of $128,800 per QALY.

One-Way Sensitivity Analyses

In one-way sensitivity analysis (Web Appendix 2), the cost-effectiveness of in-home AEDs was sensitive to the

Table 1 Cost-effectiveness of in-home AEDs and ICDs compared with EMS-D

Strategy	Cost ($)	Life-years gained	Effectiveness (QALYs)	Incremental Cost* ($)	Incremental effectiveness* (life-years)	Incremental effectiveness* (QALYs)	Cost per QALY gained* ($)
EMS-D	75,305	6.59	5.76	Na	Na	Na	Na
AED	80,530	6.66	5.81	5,225	0.07	0.05	104,500
ICD	189,965	7.73	6.66	114,660	0.98	0.90	127,400

*Compared with EMS-D.

AED, automated external defibrillator; EMS-D, emergency medical services equipped with defibrillator; ICD, implantable cardioverter defibrillator; Na, not available; QALY, quality-adjusted life-year.

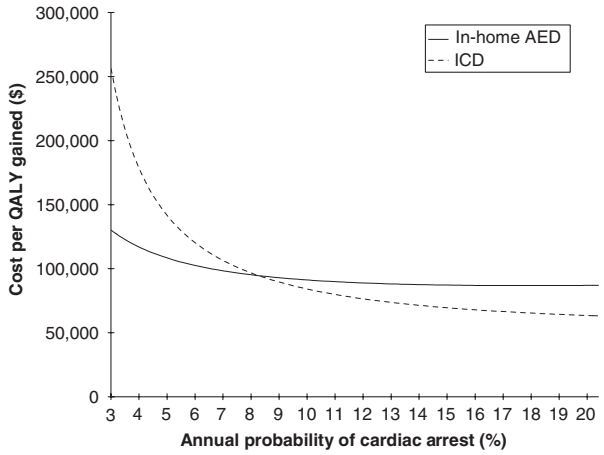

Figure 2 One-way sensitivity analysis involving probability of cardiac arrest. AED, automated external defibrillator; ICD, implantable cardioverter defibrillator; QALY, quality-adjusted life-year.

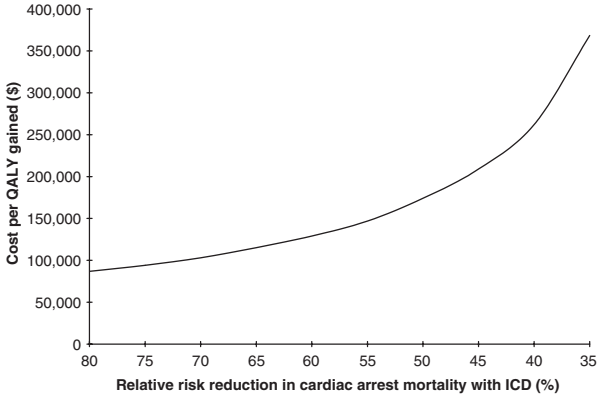

Figure 4 One-way sensitivity analysis involving the effectiveness of ICD. ICD, implantable cardioverter defibrillator; QALY, quality-adjusted life-year.

probability that an in-home AED was used and the purchase cost of the in-home AED. In addition, the cost-effectiveness of AEDs and ICDs was sensitive to the probability of cardiac arrest; AEDs remain undominated by ICDs so long as the annual probability of cardiac arrest was less than 8% per year (Fig. 2). The incremental cost-effectiveness of ICDs relative to AEDs fell below $100,000 per QALY when the annual risk of cardiac arrest was 8% or greater, but never fell below $50,000; thus, ICDs weakly dominated AEDs when the probability of cardiac arrest exceeded 8% per year.

The cost-effectiveness of AEDs was also sensitive to changes in the absolute survival benefit that the AED afforded relative to EMS-D care (Fig. 3). In the base-case, it was assumed that cardiac arrest survival increased from 15% with EMS-D to 30% with an AED; as the probability of survival with an in-home AED increased from 20% to 50% (holding survival with EMS-D constant at 15%), the cost per QALY gained of AEDs, relative to EMS-D, declined from $230,500 to $68,500.

In one-way sensitivity analysis, the cost-effectiveness of ICDs relative to EMS-D was sensitive to the annual probability of ICD-related complications and the effectiveness of ICDs in reducing cardiac arrest mortality. For example, as the annual risk of ICD-related complications increased from 1% to 10%, the cost per QALY gained increased from $78,000 to $189,000. As the relative risk reduction of cardiac arrest afforded by an ICD decreased from 80% to 30%, the cost per QALY gained increased from $86,800 to $477,500 (Fig. 4). The cost-effectiveness of ICDs was also somewhat sensitive to reductions in the cost of ICD implantation; as the cost of elective ICD implantation was reduced from $60,000 to $20,000, the cost per QALY gained decreased from $159,800 to $95,000.

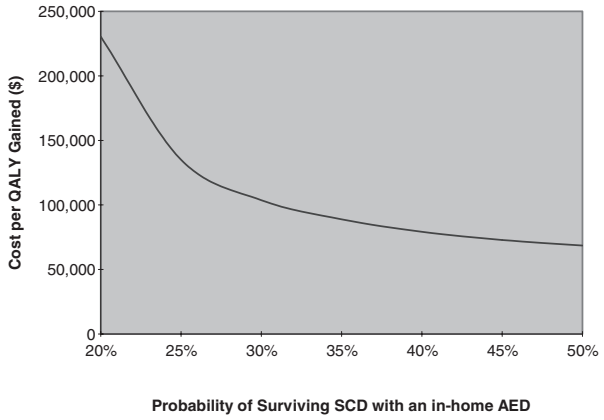

Figure 3 One-way sensitivity analysis involving the effectiveness of an in-home AED. AED, automated external defibrillator; QALY, quality-adjusted life-year.

Multi-Way Sensitivity Analysis

In Monte Carlo simulation, the median incremental cost-effectiveness for in-home AEDs and ICDs compared with EMS-D were $93,200 per QALY (mean $119,000 [interquartile range: $76,200 to $121,800]) and $131,000 per QALY (mean $133,200 [interquartile range: $104,800 to $158,300]), respectively.

Societal Impact of Alternative Distribution Strategies

First, it was necessary to estimate 2002 ICD-related expenditures. This was done by multiplying the number of Medicare beneficiaries who received ICDs in 2002 (40,000) by the lifetime cost of an ICD ($114,660) as calculated by our decision model; this resulted in a budget of $4.58 billion for defibrillators in 2002. This budget could be used to purchase 40,000 ICDs (as was done in 2002) or 876,000 AEDs. Pro-

Table 2 Societal impact of "capping" defibrillator expenditures

	Budget ($)	Incremental cost per device* ($)	QALYs gained	Devices purchased	Total QALYs gained
AEDs	4,580,000,000	5,225	0.05	876,560	43,830
ICDs	4,580,000,000	114,380	0.90	40,000	36,000

*Lifetime incremental cost compared with EMS-D based care.
AED, automated external defibrillator; EMS-D, emergency medical services equipped with defibrillator; ICD, implantable cardioverter defibrillator; QALY, quality-adjusted life-year.

viding 40,000 individuals with ICDs would be likely to produce 36,000 QALYs, while 876,560 individuals with AEDs would result in a gain of 43,830 QALYs (Table 2). Thus, at equivalent costs, home AEDs provide a greater population-wide gain in QALYs. Alternatively, for every $million spent on reducing cardiac arrest mortality, 1.7 additional QALYs are produced if AEDs are purchased (9.6 QALYs/$million) instead of ICDs (7.9 QALYs/$million).

Discussion

Interpretation of the results of our analysis is complex. ICDs are substantially more effective (6.66 QALYs per person) than either AEDs (5.81 QALYs) or EMS-D (5.76 QALYs) and have a similar cost-effectiveness ratio to AEDs when compared with EMS-D ($127,400 per QALY for ICDs; $104,500 for AEDs); from a traditional cost-effectiveness perspective, this would make ICDs the preferred technology in most circumstances. Nevertheless, in an era of increasingly constrained federal budgets and growing population of patients at risk for cardiac arrest, our exploratory analyses are provoking. From this perspective, society might reap similar or greater value from using resources to provide the less effective but less expensive AEDs (9.6 QALYs per $1 million) to many patients as opposed to providing far fewer patients with the more effective but more expensive ICDs (7.6 QALYs per $1 million), as was envisioned by Kent et al. when proposing a role for "decremental cost-effectiveness" [73].

The challenges of shifting from a strategy of maximizing QALYs gained per person to one of maximizing QALYs per dollar in expenditures would be significant. Adoption of such a strategy would require a decision by legislators and the public that rationing of health care is necessary in some form [74]. Although rationing is explicit in many countries [75,76], efforts to make the process opaque in the United States have routinely failed [77].

Even if rationing of expensive medical technologies such as ICDs were accepted as necessary, implementing such a strategy would be difficult. One method might involve a three-tiered system for reducing cardiac arrest mortality. Individuals at low or moderate risk for cardiac arrest could be treated with conventional medical therapy supplemented by EMS-D. Individuals at high risk might be given an in-home AED, while individuals at highest risk would be given ICDs. Implementing such a strategy would first require determining an available budget for reducing cardiac arrest mortality. Next, analysts would need to determine the distribution of risk among the population and then decide how many ICDs and AEDs should be purchased to maximize the value to society subject to budgetary constraints. Finally, decision rules would need to be developed to allow clinicians to accurately assess each individual's risk and make treatment recommendations.

Following such a strategy of risk-based prevention of cardiac arrest would have certain advantages. First, available data suggest that patients at the highest risk for cardiac arrest receive the greatest benefit from ICDs, making ICDs most cost-effective in this patient population. Second, such a strategy would allow society to provide AEDs to hundreds of thousands of individuals at increased risk for cardiac arrest each year, who do not qualify for ICDs including individuals with diabetes and hypertension [78].

Alternative strategies that are informed by cost-effectiveness analysis should also be considered. For example, payors might consider making a defined monetary contribution for each patient with cardiac arrest risk factors; then, the patient and their providers could jointly decide how to allocate that money (i.e., patients choose EMS-D and pocket the contribution of their payor, or choose an AED or ICD and pay for any amount above the payor's contribution). Alternatively, payors might adopt the so-called "benefit-based copay" where individuals at highest risk for cardiac arrest would have minimal copays for ICDs while individuals at lower risk would face larger copays [79]. Implementation of any strategy based on cost-effectiveness would need to take into account limitations in the methodology. In particular, policymakers would need to insure that any such system takes into account the importance of patient preferences for the various interventions that cannot be accounted for by the models.

In interpreting our results, it is important to recognize that our assumptions regarding the effectiveness of AEDs were deliberately conservative. For example, the model assumed that an in-home AED would be

used only on the individual for whom the device was purchased, but recent data have demonstrated that in actuality, in-home AEDs are used on visitors and family members [80]. In addition, we assumed that AEDs were used only at home and were never used outside the home, despite the fact that AEDs are portable [81]. The analysis also failed to include passive benefits (a.k.a. reassurance value) that in-home AEDs might provide [82]. Finally, by purchasing 500,000 AEDs per year, in a matter of years, the country could be "blanketed" with devices, thus truly moving PAD from an abstraction to a reality. All of these factors would add to the value of AEDs.

The results of the current study should be considered in light of other recent economic evaluations of ICDs that have also been based on data from the MADIT II Trial (Table 3). We found ICDs to be both less effective and more expensive than a number of prior studies [13,14,51]; this appears to be due to a number of small but significant differences among the models. First, our model assumed that ICDs reduce cardiac mortality but slightly increased noncardiac mortality, an assumption that is supported by prior studies [20,21,83]. Second, our model more comprehensively accounted for the incidence and costs of ICD-related complications than prior studies [14]. Inclusion of such complications is important, as evinced by the recent high-profile recalls of tens of thousands of AEDs by device manufacturers after revelation of device malfunctions [84,85]. Third, we assumed that ICDs were slightly more expensive than some of the other analyses. Accounting for these differences reduced the discrepancy between the results of our analysis and those of Sanders et al., but did not eliminate them; this underscores the importance of transparency in reporting decision analysis and adhering to guidelines [10]. It is also important to recognize that the cost-effectiveness of ICDs would be reduced if ICDs prove less effective in general practice than in clinical trials or if coverage is expanded to patients at lower risk for cardiac arrest. Finally, it is important to recognize that over time technology is likely to improve resulting perhaps in both improved effectiveness of AEDs and ICDs as well as reductions in cost that are likely to change the balance between these devices.

The current study has a number of limitations. First, the model was populated with a cohort of patients with ischemic cardiomyopathy and an ejection fraction of less than 30% meeting entry criteria for the MADIT II Trial; the model relied on published data regarding the average cardiac arrest and noncardiac arrest mortality rates from the trial despite the fact that there was certainly a distribution of mortality rates based on clinical risk factors (e.g., ejection fraction). Using a single point estimate limited our ability to precisely determine actual, cardiac arrest mortality rate thresholds where it might be cost-effective to advocate one strategy (e.g., ICDs) versus another (e.g., AEDs). In this respect, future studies pooling the results of the growing number of ICD primary-prevention trials to provide accurate estimates of risk distribution among patient populations would be most useful. Second, the cost-effectiveness of ICDs is sensitive to the annual probability of ICD-related complications, yet data on such complications are limited. Third, our analysis did not capture potential complications resulting from in-home AED deployment, but this appears to be justified based on the safety record of modern AEDs; the ongoing Home Use AED trial will help to clarify the frequency of such complications. Fourth, if the costs of ICDs decline, some of the budgetary pressure might be reduced. Fifth, a risk-based cardiac arrest prevention strategy is dependent on our ability to identify specific risk factors (e.g., T-wave alternans) for cardiac arrest in individual patients [86].

In summary, ICDs have the potential to dramatically reduce mortality in a broad spectrum of patients with cardiac dysfunction. The key to unlocking this potential lies in making these devices available to the patient populations who stand to receive the largest benefit, without hampering payors' abilities to cover both currently available therapies and future technological innovations.

Table 3 Summary of economic evaluations of MADIT II Trial

Study	Incremental cost* ($)	Incremental effectiveness (QALYs)	Cost per QALY gained ($)
Cram	114,660	0.90	127,400
Al-Khatib [13]	90,800	1.40	64,800
Sanders [14]	79,400	1.47	54,000
Chen [51]	97,900	1.00	97,900

*Compared with EMS-D.

EMS-D, emergency medical services equipped with defibrillator; QALY, quality-adjusted life-year.

Source of financial support: None. Dr Cram is supported by a K23 career development award (RR01997201) from the NCRR at the NIH.

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