Potential Cost-effectiveness of Public Access Defibrillation in the United States

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Background—Approximately 360,000 Americans experience sudden cardiac arrest each year; current treatments are expensive and not very effective. Public access defibrillation (PAD) is a novel treatment for out-of-hospital sudden cardiac arrest that refers to use of automated external defibrillators by the lay public or by nonmedical personnel such as police. A clinical trial has been proposed to evaluate the effectiveness of public access defibrillation, but it is unclear whether such early defibrillation will offer sufficient value for money. Our objective was to estimate the potential cost-effectiveness of public access defibrillation by use of decision analysis.

Methods and Results—A decision model compared the potential cost-effectiveness of standard emergency medical services (EMS) systems with that of EMS supplemented by PAD. We considered defibrillation by lay responders or police, using an analysis with a US health-care perspective. Input data were derived from published data or fiscal databases. Future costs and effects were discounted at 3%. Monte Carlo simulation was performed to estimate the variability in the costs and effects of each program. Sensitivity analyses assessed the robustness of the results to changes in input data. A standard EMS system had a median cost of $5900 per cardiac arrest patient (interquartile range, IQR, $3200 to $10,900) and yielded a median of 0.25 quality-adjusted life years (IQR, 0.20 to 0.30). PAD by lay responders had a median incremental cost of $44,000 per additional quality-adjusted life year (IQR, $29,000 to $68,900). PAD by police had a median incremental cost of $27,200 per additional quality-adjusted life year (IQR, $15,700 to $47,800). The results were sensitive to changes in the cost and relative survival benefit of PAD.

Conclusions—Although more expensive than standard EMS for sudden cardiac arrest, PAD may be economically attractive. The effectiveness and cost-effectiveness of PAD should be assessed in a randomized, controlled trial. (Circulation. 1998;97:1315-1320.)

Key Words: cost-benefit analysis ■ heart-assist device ■ heart arrest

Cardiovascular disease is the most common cause of death in North America.1,2 During the past 20 years, morbidity and mortality rates for nearly all types of cardiovascular disease have declined. However, there has been little decline in the incidence of sudden cardiac arrest. In the United States, ~1000 patients experience cardiac arrest each day.1,3 External cardiopulmonary resuscitation and defibrillation were first described as effective treatments for sudden cardiac arrest >30 years ago. However, survival after out-of-hospital cardiac arrest is still poor.4-7 The American Heart Association previously addressed this problem by emphasizing the importance of the chain of survival8: early access, early cardiopulmonary resuscitation, early defibrillation, and early advanced life support. Because early defibrillation is the single most important treatment, we previously proposed a novel defibrillation strategy that includes defibrillation by minimally trained members of the public, referred to as PAD.9 This strategy seeks to distribute AEDs at specific sites at which sudden cardiac arrest occurs frequently, such as public places where large numbers of older people are under stress (eg, airports and casinos), or to provide AEDs to nontraditional responders such as police.

Economic evaluation of a new medical technology such as PAD assesses the effectiveness and cost of the technology so that physicians and policy-makers can decide whether it offers sufficient value for money. Although a nonexperimen
tal study of enhanced defibrillation suggests that it is very effective,10 the potential costs of implementation of PAD have not been assessed. Therefore, the objective of this analysis was to estimate the potential cost-effectiveness of PAD in an urban center in the United States.

Methods

Interventions

We considered treatment of out-of-hospital sudden cardiac arrest by an EMS system (standard EMS system) or by an EMS system...
supplemented by PAD. Because PAD may be implemented by training and equipping either lay responders or police, separate analyses considered either of these programs.

**Input Data**

Data were obtained by a search of the English-language MEDLINE reference media from 1966 to 1997, under the subject heading “heart arrest,” combined with “randomized controlled trials (PT),” or “prospective studies” (Table 1). Most of these articles described cohort studies of patients who had experienced sudden cardiac arrest. This was supplemented by information from a recent nonexperimental study of the implementation of expanded defibrillation by police.

**Structure of Decision Model**

A simple decision tree was constructed to compare costs and outcomes after out-of-hospital cardiac arrest treated by each program (Fig 1). According to the decision model, a patient who experienced sudden cardiac arrest either died before hospital, died in hospital, or lived to discharge. If the EMS system was supplemented by PAD by lay responders, then patients who experienced sudden cardiac arrest in a public place potentially benefited from enhanced defibrillation. If the EMS system was supplemented by PAD by police, then all patients who experienced sudden cardiac arrest potentially benefited from enhanced defibrillation.

Probabilistic simulation was incorporated into the model as follows. A probability distribution was specified for each variable. Then Monte Carlo simulation was performed by randomly drawing the value of each variable from its corresponding distribution. Sampling was repeated 10 000 times to estimate the variability of the cost and effectiveness of each diagnostic strategy.

All analyses were performed with DATA 3.0 and spreadsheet software.

**Assumptions**

We made several assumptions about the costs of implementing and maintaining a PAD program because the magnitude of the costs of such programs is unknown at present. First, implementation of PAD would not change the costs of treatment of sudden cardiac arrest by EMS. Second, the individual cost of a defibrillator will decrease from the current list price of $3000 to $2500 as competition increases among defibrillator manufacturers. Third, the density of distribution of defibrillators in a community was such that one device was available for each cardiac arrest that occurred in public. Fourth, the

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**TABLE 1. Input Data**

<table>
<thead>
<tr>
<th>Description</th>
<th>Best Estimate</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population living in urban center, %</td>
<td>75</td>
<td>74</td>
<td>76</td>
<td>Census Bureau</td>
</tr>
<tr>
<td>Cardiac arrests that occur in public, %</td>
<td>20</td>
<td>15</td>
<td>36</td>
<td>15–18 and personal communication, L Becker</td>
</tr>
<tr>
<td>Effectiveness</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Survival from hospital admission to discharge, %</td>
<td>32</td>
<td>24</td>
<td>40</td>
<td>5</td>
</tr>
<tr>
<td>Overall survival to hospital discharge, %</td>
<td>8</td>
<td>0</td>
<td>25</td>
<td>Assumed</td>
</tr>
<tr>
<td>Relative benefit of PAD</td>
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<td>1.05</td>
<td>2.2</td>
<td>Adapted from 10</td>
</tr>
<tr>
<td>Life expectancy of survivor of cardiac arrest</td>
<td>5.61</td>
<td>4.79</td>
<td>6.62</td>
<td>19</td>
</tr>
<tr>
<td>Utility of survivor of cardiac arrest</td>
<td>0.72</td>
<td>0.68</td>
<td>0.78</td>
<td>20</td>
</tr>
<tr>
<td>Costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discount rate, %</td>
<td>3</td>
<td>0</td>
<td>10</td>
<td>Assumed</td>
</tr>
<tr>
<td>AED, $</td>
<td>2500</td>
<td>500</td>
<td>3000</td>
<td>Manufacturer’s survey</td>
</tr>
<tr>
<td>Annual training and maintenance cost, %</td>
<td>10</td>
<td>0</td>
<td>200</td>
<td>Assumed</td>
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<tr>
<td>Police defibrillation, $</td>
<td>223</td>
<td>50</td>
<td>500</td>
<td>Personal communication, R.D. White</td>
</tr>
<tr>
<td>Hospital stay for patient who dies before discharge, $</td>
<td>2809</td>
<td>254</td>
<td>31 125</td>
<td>Personal communication, L. Clark</td>
</tr>
<tr>
<td>Hospital stay for patient discharged alive, $</td>
<td>62 044</td>
<td>8742</td>
<td>440 342</td>
<td>Personal communication, L. Clark</td>
</tr>
</tbody>
</table>
training and maintenance costs for the PAD program were equivalent to 10% of the total device costs.

Each variable in the decision model was modeled with the distribution that best described the underlying physical process, because the true value of the variables was unknown. The proportion of sudden cardiac arrests that occur in public was modeled as a triangular distribution. For standard EMS systems, the probability of survival was modeled as a $\beta$-distribution. The relative benefit of PAD compared with a standard EMS system was modeled as a triangular distribution. Finally, cost variables were modeled as triangular or log-normal distributions.

### Data

#### Outcomes

The probability of each outcome associated with standard EMS or PAD was derived from the literature review described above (Table 1). For standard EMS systems, the probability of survival to hospital admission was derived from a meta-analysis of the effectiveness of resuscitation for out-of-hospital cardiac arrest. Then the probability of survival from admission to discharge was calculated, so that the overall survival to hospital discharge was 8%. The relative benefit of PAD compared with standard EMS systems was based on a case-control study of provision of early defibrillation by police. Life expectancy after discharge from hospital was calculated from a large cohort of survivors of cardiac arrest, by use of a declining exponential approximation of life expectancy. The quality of life of survivors of cardiac arrest was estimated from a recent prospective study of the health-related quality of life of survivors of cardiac arrest.

#### Costs

The economic perspective was that of society. All costs were expressed in 1996 American dollars (Table 1). Capital costs of equipment were discounted over their anticipated lifespan, with a discount rate of 3%. The cost of police defibrillation was estimated from the budget of the police defibrillation program in Rochester, Minn (Appendix). The costs of hospitalization were derived from a cohort of patients who were treated at a single medical center after experiencing out-of-hospital cardiac arrest in Tucson, Ariz, in 1996, stratified according to whether the patients survived to hospital discharge (personal communication, L. Clark, August 20, 1997). Then the net cost of any outcome (ie, death before hospital, death in hospital, or survival to discharge) was calculated as the sum of the costs of prehospital care and in-hospital care.

The cost of treatment by the EMS system was not included in the analysis because it was common to both strategies. Future costs were not included in the analysis because of ongoing controversy about inclusion of such costs in an economic evaluation and lack of information about the true value of such costs.

A secondary analysis considered only the immediate costs of PAD (ie, the costs incurred in providing the treatment itself). Such a restricted perspective was considered because the costs of providing EMS, hospitalization, or subsequent care are not relevant to stakeholders, such as municipal governments, who pay only for police services.

### Sensitivity Analyses

One-way sensitivity analyses evaluated the robustness of the results as follows. We substituted the upper and lower limits of the value of each variable in the decision model while holding all other values constant (Table 1). For empirical variables (eg, cost of hospitalization), these upper and lower limits were considered to be equivalent to the 95% confidence limits for the value of each variable. For assumed or estimated variables (eg, overall survival in standard EMS system, cost of a defibrillator, cost of implementing and maintaining the defibrillator program, and discount rate), the upper and lower limits were based on reasonable possible limits. Threshold analyses were conducted to identify the value of each variable across its range, if any, at which one should be indifferent between standard EMS or PAD (ie, the costs and outcomes of the two strategies were equal). Multiway sensitivity analyses were also performed as follows. Because the effectiveness of standard EMS and of PAD may be correlated, we varied these characteristics simultaneously. Because the costs of implementing and maintaining a PAD program may vary together, we also varied the value of these variables simultaneously.

### Results

#### Cost-effectiveness of PAD

The analyses suggested that in an urban EMS system with an overall survival of 8%, implementation of PAD by lay responders was associated with a median incremental survival of 0.7% (IQR, 0.5% to 0.9%) (Table 2). Compared with a standard EMS system, PAD was associated with a median cost of $44 000 (IQR, $29 000 to $68 900) per additional quality-adjusted life year.

In an urban EMS system with an overall survival of 8%, implementation of PAD by police was associated with a median cost of $27 200 (IQR, $15 700 to $47 800) per additional quality-adjusted life year compared with a standard EMS system (Table 3).
When only the immediate costs of defibrillation by police were considered, implementation of PAD was associated with a median cost of $6500 (IQR, $4300 to $9700) per additional quality-adjusted life year compared with a standard EMS system in an urban EMS system with an overall survival of 8% (Table 4).

### Sensitivity Analyses

The difference between the costs and outcomes of PAD compared with standard EMS systems was not affected by reasonable univariate changes in values for most variables. Because the results of the sensitivity analyses were similar for either type of PAD program, we will focus on the robustness of the results for police defibrillation.

To place the incremental cost-effectiveness of police defibrillation in perspective, we considered a range of possible values for survival with standard EMS systems and relative benefit of police defibrillation (Fig 2). As the rate of survival with standard EMS systems increases, the cost per additional quality-adjusted life year decreases. Also, as the relative benefit of PAD increases, the cost per additional quality-adjusted life year decreases.

The results of the analysis were also sensitive to changes in the costs of the defibrillation program or hospitalization. For example, PAD by police cost more than $50 000 per additional quality-adjusted life year compared with standard EMS systems if the immediate cost of defibrillation was 10 times its baseline value or if the costs of hospitalization were 1.5 times their baseline values.

In summary, the results of the analysis were sensitive to very large changes or simultaneous changes in the value of several variables in the decision model.

### Impact on Public Health

The United States has a population of 267 792 000 people. Of these, 85% live in an urban center; 27% are >50 years old.29 The annual incidence of sudden cardiac arrest among people ≥50 years old in Seattle, Wash, is 0.7% (personal communication, A. Hallstrom, August 15, 1997); 20% of cardiac arrests occur in public places; the average survival to hospital discharge after out-of-hospital sudden cardiac arrest is ≈8%.

If PAD has a relative benefit of 1.5, implementation of defibrillation by lay responders may save >4065 additional lives annually. Alternatively, implementation of defibrillation by police may save >20 000 additional lives annually.

### Discussion

Our analysis shows that implementation of PAD in an urban center in the United States is potentially economically attractive. Furthermore, defibrillation of out-of-hospital sudden cardiac arrest patients by lay or police responders may save the lives of thousands of Americans each year. These represent important potential public health benefits.

The cost-effectiveness of PAD was sensitive to changes in the value of several variables in the decision model. In particular, the results were sensitive to changes in the proportion of patients who survive cardiac arrest and the costs of implementing and maintaining PAD. Therefore, decisions about implementation of a PAD program in an individual community should consider the survival achieved by the existing EMS system and the costs of the program.

This analysis is consistent with a previous cost-effectiveness analysis of EMS, which suggested that improvements that decrease the time to defibrillation were economically attractive.3 However, there are some important differences between these two analyses. First, the previous analysis considered only improvements to existing EMS systems, rather than introduction of enhanced defibrillation by nontraditional responders. Second, the previous analysis based estimates on a single study. Despite the differences between these economic evaluations, collectively they suggest that methods of decreasing the time between onset of out-of-hospital cardiac arrest and defibrillation are potentially economically attractive.

The potential costs and outcomes of PAD estimated by this analysis should be interpreted cautiously. However, the incremental cost per additional quality-adjusted life year is similar to that of other common medical interventions (ie, <$50 000 per quality-adjusted life year).36 If PAD is as effective and inexpensive as we believe, then it will be economically attractive compared with other interventions.

Our estimate of the effectiveness of PAD was derived from a nonexperimental study of the impact of enhanced defibrillation. This study evaluated use of defibrillators by police...
who were targeted responders to cardiac emergencies, rather than use by minimally trained members of the public. At present, there are no published data that describe the effect of use of defibrillators by the public on time to defibrillation or on survival. However, implementation of enhanced defibrillation in casinos in the United States has been associated with a large decrease in the time interval between the onset of cardiac arrest and the provision of defibrillation (personal communication, T. Valenzuela, June 27, 1997). Experimental studies are now necessary to demonstrate whether PAD is an effective and cost-effective treatment, because outcomes after cardiac arrest may be influenced by several factors.31

This analysis used Monte Carlo simulation to evaluate the magnitude of uncertainty in the cost-effectiveness of PAD.27 The range of the incremental cost-effectiveness of PAD was very large because the value of several input variables was highly uncertain. Furthermore, the distribution of the results was skewed because several of the input variables were not normally distributed. However, if the incremental cost of PAD is as low as $15 700 per quality-adjusted life year, then the program will be quite economically attractive. Conversely, if the incremental cost of PAD is as high as $68 900 per quality-adjusted life year, then the program may not be economically attractive. Therefore, any experimental study of the cost-effectiveness of PAD should have sufficient power to detect a meaningful economic difference.32

This analysis may have overestimated the incremental cost-effectiveness of PAD (ie, may have been biased against finding it economically attractive), for several reasons. First, the proportion of cardiac arrests that occur in public was close to the lower end of the range of values reported. Second, we deliberately underestimated the relative effectiveness of PAD compared with the relative effectiveness of enhanced defibrillation that was reported by White et al10 (relative benefit, 2.2).

There are several limitations to this analysis. First, the input data were derived from several sources. Because multiple sources were used, these estimates may be confounded by information that was not incorporated into the model. For example, the effectiveness of resuscitation was not adjusted for the response time interval. Second, we assumed that the costs of EMS systems were equivalent between the two strategies. However, it is plausible that implementation of PAD may increase the costs of EMS systems, because the number of patients who experience restoration of circulation in the field will increase. Finally, it is unlikely that the relative benefit of defibrillation will be constant as the proportion of patients who survive with standard EMS systems increases. Therefore, our analysis should be revised to reflect better estimates of the true effectiveness and costs of the program as results from trials of enhanced defibrillation become available.

Conclusions

Implementation of PAD in the United States is potentially associated with an incremental cost-effectiveness ratio similar to other common medical interventions. Therefore, a randomized, controlled trial is necessary to evaluate the effectiveness and cost-effectiveness of expanded use of defibrillation in sudden cardiac arrest.

Appendix

Costs of Police Defibrillation

The costs of implementing PAD by police responders were based on the costs of the police defibrillation program in Rochester, Minn (personal communication, Roger D. White, August 20, 1997). This program serves 40 cardiac arrest cases among 60 000 calls annually in a geographic area of 32.6 square miles. Each police officer requires $100 of initial training in rapid defibrillation and $35 of retraining every 4 months. An average of 10 vehicles are staffed 24 hours per day and 7 days per week. Each vehicle costs $19 254 to purchase and has annual costs of $3900 during a 2-year lifespan. Each vehicle is staffed by one police officer who receives annual salary and benefits of $43 963. Allowing for vacation and sick time, 5.2 full-time equivalents are needed to staff each vehicle. Of the $9.8 million police department budget, 10% is used to provide administrative support. The costs of police defibrillation were calculated by adding the training and equipment costs to the wage, administrative, and vehicle costs. These latter costs were allocated to the defibrillation program by multiplying by the ratio of cardiac arrest cases to total call volume. Thus, the net cost of the police defibrillation program is $223 per cardiac arrest.

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13. TreeAge Software I. Decision Analysis by TreeAge. 3.0 ed. Boston, Mass: TreeAge Inc; 1996.


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