The Cost-effectiveness of Automatic Implantable Cardiac Defibrillators: Results From MADIT

Alvin I. Mushlin, MD, ScM; W. Jackson Hall, PhD; Jack Zwanziger, PhD; Elizabeth Gajary, MA; Mark Andrews, BBA; Rebecca Marron, MPH; Kelly H. Zou, PhD; Arthur J. Moss, MD; for the MADIT Investigators*

Background—The recently reported Multicenter Automatic Defibrillator Implantation Trial (MADIT) showed improved survival in selected asymptomatic patients with coronary disease and nonsustained ventricular tachycardia. The economic consequences of defibrillator management in this patient population are unknown.

Methods and Results—Patients were followed up to quantify their use of healthcare services, including hospitalizations, physician visits, medications, laboratory tests, and procedures, during the trial. The costs of these services, including the costs of the defibrillator, were determined in patients randomized to defibrillator and nondefibrillator therapy. Incremental cost-effectiveness ratios were calculated by relating these costs to the increased survival associated with the use of the defibrillator. The average survival for the defibrillator group over a 4-year period was 3.66 years compared with 2.80 years for conventionally treated patients. Accumulated net costs were $97 560 for the defibrillator group compared with $75 980 for individuals treated with medications alone. The resulting incremental cost-effectiveness ratio of $27 000 per life-year saved compares favorably with other cardiac interventions. Sensitivity analyses showed that the incremental cost-effectiveness ratio would be reduced to $23 000 per life-year saved if transvenous defibrillators were used instead of the older devices, which required thoracic surgery for implantation.

Conclusions—An implanted cardiac defibrillator is cost-effective in selected individuals at high risk for ventricular arrhythmias. (Circulation. 1998;97:2129-2135.)

Key Words: cost-effectiveness • cardioversion • defibrillation

Sudden cardiac death claims almost a half million lives in the United States per year and occurs mostly in patients with underlying coronary artery disease.1 Ventricular arrhythmias are believed to be the major cause of such deaths. Prevention of sudden death in high-risk patients has been the focus of much attention and has resulted in the development of medications and technologies for this purpose. These include new antiarrhythmic agents, electrophysiological testing, and implantable cardiac defibrillators (ICDs). To date, the usefulness of antiarrhythmic medications has been disappointing.2–4 During this same time, ICDs have evolved to the point that they are smaller and easier to implant than the older devices, which required a thoracotomy.

The recently reported Multicenter Automatic Defibrillator Implantation Trial (MADIT) has shown for the first time that an ICD reduces all-cause mortality in patients at high risk for ventricular arrhythmias.5 Because the economic consequences of defibrillator management are an important issue, an evaluation of costs was performed as an integral part of the trial itself. We report the results of this cost-effectiveness analysis.

Methods

Overview of MADIT

In MADIT, 196 patients were enrolled from 38 centers (36 in the United States and 2 in Europe). The cost-effectiveness analysis was based on the 181 patients from the United States.

Patients eligible for MADIT were those with asymptomatic nonsustained ventricular tachycardia, a prior myocardial infarction, an ejection fraction ≤35%, and an inducible ventricular tachyarrhythmia at electrophysiological testing that was not suppressed by procainamide.5 Patients were randomly assigned to receive either an ICD or conventional medical therapy. The enrollment procedures, clinical follow-up, and results have been described in the primary publication.5

When the trial started in December 1990, only transthoracic implants were approved for use. Nonthoracotomy transvenous leads were incorporated into the trial in August 1993. The trial used a sequential stopping rule, with weekly data analyses until a stopping boundary was reached. The trial ended in March 1996, with an
Estimated reduction of 54% in the mortality rate (a hazard ratio of 0.46), at a \( P \) value of .009.  

The first enrolled patient was followed up for 61 months and the last for 14 months. The average duration of follow-up for the 181 patients in the cost-effectiveness substudy was 27 months, with an average of 37 months for patients recruited when the earlier transthoracic device was being used (\( n = 98 \)) and 14 months for the later transvenous period (\( n = 83 \)).

### Methods for Economic Evaluation

#### Utilization Information

The methods and procedures used for the collection of utilization data and economic information have been described previously. Each month, nurse coordinators queried patients regarding their healthcare use, including hospitalizations, emergency room visits, office visits to physicians and specialists, outpatient diagnostic tests and procedures, community services, medical supplies, and prescription medications. At the first clinic visit, patients provided their healthcare use for the year before randomization.

The nurse coordinator obtained an itemized bill or a copy of the Uniform Billing Form (UB 82/92) from the hospital for all hospitalizations and emergency room visits. Physician visits were coded as brief, intermediate, or extended. Outpatient diagnostic tests and procedures included all reported radiographs, diagnostic procedures, blood tests, and therapeutic procedures. Community services were all supplies, ambulance services, home and nursing home care, and physical or occupational therapy.

#### Data Completion

Patients reported 697 hospitalizations; billing information was obtained for all but 14 (2%) (Table 1). There were 82 reported emergency room visits, with billing information for all but 6 (7%). Patients reported 5203 visits (including protocol study visits) to primary care physicians, cardiologists, and other specialists and 6324 outpatient diagnostic tests or procedures (9 [0.1%] missing). This patient population reported taking 471 distinct medications; for 20 cases (4%), we had insufficient detail to code the entry. There were 214 separate services or supplies used.

#### Sources for Costs and Charges

The methods used to translate utilization data into costs are summarized in Table 2. All costs were adjusted to 1995 dollars on the basis of the medical consumer price index. For inpatient hospital stays, we converted charges from patient bills or UB82 forms into costs using hospital-specific cost-to-charge ratios. The costs of the corresponding physician services were based on a national study of Medicare claims that calculated the ratio of physician to hospital costs for each Diagnosis Related Group (DRG). Emergency department costs were calculated similarly, with the facility component derived from a cost-to-charge ratio and total billed charges. Emergency physician costs were imputed on the basis of payment rates in the Medicare Resource Based Relative Value

### Tables

#### Table 1. MADIT Cost-effectiveness Study: Data Completion

<table>
<thead>
<tr>
<th></th>
<th>Total Reported</th>
<th>Conventional Therapy*</th>
<th>ICD†</th>
<th>Total Missing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hospitalizations:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>patient bills/UB-82/92</td>
<td>697</td>
<td>323 (13)</td>
<td>360 (1)</td>
<td>14</td>
</tr>
<tr>
<td>Emergency department visits: UB-82/92</td>
<td>82</td>
<td>30 (3)</td>
<td>46 (3)</td>
<td>6</td>
</tr>
<tr>
<td>Physician visits</td>
<td>5203</td>
<td>2275 (0)</td>
<td>2928 (0)</td>
<td>0</td>
</tr>
<tr>
<td>Outpatient tests/procedures</td>
<td>6324</td>
<td>3175 (5)</td>
<td>3140 (4)</td>
<td>9</td>
</tr>
<tr>
<td>Medications</td>
<td>676</td>
<td>316 (6)</td>
<td>340 (11)</td>
<td>20</td>
</tr>
<tr>
<td>Other disease/treatment-related service</td>
<td>214</td>
<td>93 (0)</td>
<td>121 (0)</td>
<td>0</td>
</tr>
</tbody>
</table>

ICD indicates implantable cardiac defibrillator; UB, uniform billing form.  
*92 patients in the conventional therapy group, with 2254 person-months of observation.  
†89 patients in the defibrillator (ICD) group, with 2577 person-months of observation.  
Numbers in parentheses represent numbers of missing data.

#### Table 2. MADIT Cost-effectiveness Study: Cost Data

<table>
<thead>
<tr>
<th>Patient-Reported Utilization</th>
<th>Coded Information</th>
<th>Cost/charge ratios from Medicare cost reports; MD component using DRGs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hospitalization and emergency department visits</td>
<td>UB-82s Revenue codes ($)</td>
<td>DRG LOS</td>
</tr>
<tr>
<td>Outpatient tests and procedures</td>
<td>CPT-95</td>
<td>Medicare rates</td>
</tr>
<tr>
<td>Physician/specialist visits</td>
<td>Visit complexity</td>
<td>RBRVUs and Medicare rates</td>
</tr>
<tr>
<td>Community services</td>
<td>Revenue codes</td>
<td>Medicare rates</td>
</tr>
<tr>
<td>Medical supplies</td>
<td>Supply codes</td>
<td>Medicare and Medicaid rates</td>
</tr>
<tr>
<td>Medications</td>
<td>NDC</td>
<td>Average wholesale price</td>
</tr>
</tbody>
</table>

*1995 dollars.
Scale (RBRVS) together with its geographic adjustors. Office visits were valued on the basis of the RBRVS with its geographic adjustors. We calculated the costs of outpatient tests using the Medicare payment scale for each Current Procedural Terminology code. The costs of community, medical, and social services and supply costs were based on the 1995 Health Care Financing Administration Common Procedure Coding System Medicare codes in each Medicare area or Medicaid payment rates for those services or supplies not reimbursed by Medicare. Finally, pharmaceutical costs were derived by use of the average wholesale prices for each medication as indicated in the 1995 Drug Topics Red Book.

Statistical Methods

Analyses were restricted to a 4-year period because cost data beyond 4 years were sparse, with only 8 patients completing a fifth year in the study. Cost and utilization data were assembled and summarized in the following time periods: prior year (−1), initial (0), 1 month (1), 3 months (2), 6 months (3), 9 months (4) . . . 48 months (17), with each period accumulating costs reported since the previous period. Costs in a period were averaged over patients observed during the period.

To summarize cost comparisons between the two arms without regard to survival effects, we determined costs in each time period (periods 1 to 17, averaging over surviving patients in the respective arms), and then averaged over the 17 periods (weighting proportionally to period lengths). To assess statistical significance, we used bootstrap resampling, as described below.

The cost-effectiveness analyses used methods that allowed for varying levels of censorship. A discounted years-of-life-saved measure was computed, representing the difference in life expectancy (within 4 years) between patients in the defibrillator and conventional therapy arms. This measure can be visualized as the area between the two Kaplan-Meier survival curves (similar to those in the primary paper) over the period 0 to 4 years, except that a 3% per annum discount factor was applied.

Discounted differential costs (within 4 years) were computed as follows. For each period (0 to 17), the average costs in the period were determined, multiplied by the Kaplan-Meier estimate of survival through that period, multiplied by a discount factor (3% per annum), and then accumulated over periods. The result is the "net present value" of accumulated costs. The difference between these two quantities, one for each arm of the trial, represents the expected difference in costs (within 4 years) incurred by a patient in the defibrillator arm compared with a patient in the conventional therapy arm.

The ratio of differential costs to survival is the incremental cost-effectiveness ratio (iCER): ICER=x/y, with y the differential discounted accumulated cost and x the discounted years of life saved (both x and y limited to a 4-year span). The incremental cost-effectiveness ratio represents the extra cost incurred to save 1 year of life within 4 years for patients randomized to defibrillator rather than conventional therapy.

Published methods for quantifying variability are not appropriate here because they treat only the case of nonrandom cost data. We instead used a bootstrap analysis with 1000 bootstrap resamplings. This produces 1000 (x,y) pairs: an estimated years of life saved (x) and an estimated differential 4-year cost (y). This mimics results that would be obtained if 1000 studies identical to MADIT were performed and provides a basis for construction of confidence intervals.

Because costs subsequent to the initial hospitalization were relatively flat over time, we also determined average monthly costs (by type) for each patient in the study, whether observed for 1 month or 61 months. These numbers were analyzed by rank sum tests to compare the two treatment arms and by regression methods (after logarithmic transformations) to explore possible explanatory variable dependencies.

Results

Study Population

The patients randomized to the ICD group were comparable to those who were assigned to receive conventional medical therapy. The use of medical services and hospital expenditures over the year before entry into the trial were also similar in the two treatment groups (Figure 1).

Five patients randomized to receive the ICD did not in fact have a device implanted. Eleven patients crossed over from conventional therapy and received an ICD at varying times during the trial. Cost-effectiveness analyses used the intention-to-treat principle.

Medical Care Use and Costs

Total costs per patient month are plotted in Figure 1 and enumerated in Table 3. The average initial costs of $44 600 experienced by the ICD group were considerably higher than those for the conventionally treated patients ($18 900). This difference of $25 700 is attributable to the cost of the device and the implantation procedure. Over the subsequent months of the trial, there was a tendency for conventionally treated individuals to have higher costs. This resulted in average monthly costs, after the initial hospitalization, for surviving patients of $1915 for conventionally treated patients compared with $1384 for those assigned to the device (difference not statistically significant).

Figure 2 shows that medication costs after the initial 30-day period were higher for conventionally treated patients than for defibrillator patients throughout the 48-month follow-up (P =0.03). The average medication costs were $266/mo in the conventional therapy group versus $182/mo in the ICD group (Table 3). No additional explanatory variables, either demographic or clinical, were associated with total subsequent costs.

The categories of medical care used and their costs were highly variable from patient to patient. Additionally, there
were no clear patterns or differences between the two treatment arms other than our observation that the conventional therapy patients had somewhat higher expenditures for antiarrhythmic medications and the ICD patients had somewhat higher expenditures for other types of cardiac medications. We found no other explainable (or significant) differences in the categories of subsequent use or expenses between the groups.

Because ICD patients lived longer, they accumulated costs over longer periods. The net present value in 1995 dollars for treating patients with an ICD during the 4 years of the trial is estimated to be $97,560 compared with $75,980 for the conventional therapy group (line 1 of Table 4). These higher costs are almost entirely due to longer survival because the lower monthly cost in the ICD group overcomes the higher initial cost in 4 years.

Survival
The survival experienced by the ICD group was significantly better than that in the conventionally treated patients. On average, a person treated with an ICD could expect to survive 3.66 out of 4 years and those treated conventionally 2.80 out of 4 years. The survival discounted to present value was 3.46 years for the ICD and 2.66 years for the conventional therapy group. The benefit attributable to the ICD is the difference between these, or 0.80 years out of 4 (line 2 of Table 4).

Cost-effectiveness Ratios
The increased survival of 0.80 years for the ICD group was associated with an incremental cost of $21,580. The resulting incremental cost-effectiveness ratio (Table 4) is $27,000 per life-year saved.

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**TABLE 3. MADIT Cost-effectiveness Study: Average Costs and Utilization for Conventional Therapy and ICD Patients**

<table>
<thead>
<tr>
<th>Type</th>
<th>Conventional Therapy (N=92)</th>
<th>ICD (N=89)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total initial costs*</td>
<td>$18,880</td>
<td>$44,565</td>
</tr>
<tr>
<td>Initial hospitalization†</td>
<td>$18,880</td>
<td>$24,775</td>
</tr>
<tr>
<td>Cost of defibrillator</td>
<td>0</td>
<td>$19,790†</td>
</tr>
<tr>
<td>Subsequent costs (per month)§</td>
<td>$1915</td>
<td>$1384</td>
</tr>
<tr>
<td>Hospital</td>
<td>$1376</td>
<td>$982</td>
</tr>
<tr>
<td>Emergency room</td>
<td>$8</td>
<td>$12</td>
</tr>
<tr>
<td>Physician visits</td>
<td>$80</td>
<td>$88</td>
</tr>
<tr>
<td>Medications</td>
<td>$266</td>
<td>$182</td>
</tr>
<tr>
<td>Community services</td>
<td>$78</td>
<td>$25</td>
</tr>
<tr>
<td>Medical supplies</td>
<td>$1</td>
<td>$2</td>
</tr>
<tr>
<td>Outpatient diagnostic tests</td>
<td>$99</td>
<td>$91</td>
</tr>
<tr>
<td>Other</td>
<td>$8</td>
<td>$2</td>
</tr>
<tr>
<td>Subsequent hospitalizations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number per year</td>
<td>1.12</td>
<td>1.03</td>
</tr>
<tr>
<td>Days per year</td>
<td>8.1</td>
<td>6.3</td>
</tr>
</tbody>
</table>

ICD indicates implantable cardiac defibrillator.

*Initial period is the 30-day interval after randomization to conventional or defibrillator therapy.
†Including all costs, except the cost of a defibrillator, associated with the initial hospitalization (or outpatient visit). The difference of $5895 between conventional therapy and ICD is statistically significant (P = 0.003 by a Wilcoxon rank sum test and P = 0.002 by bootstrap). No other explanatory variables were identified.
‡84 of the 89 patients in the ICD arm received defibrillators at the initial hospitalization; costs here are averaged over all 89 patients.
§For subsequent months, reported averages are weighted averages over periods 1-17 of the period-specific costs, the latter being averaged over patients available in respective periods; see “Methods.” Comparing conventional therapy with ICD, P = 0.03 (bootstrap based) for subsequent medications and P > 0.1 for all other subsequent uses.

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**TABLE 4. MADIT Cost-effectiveness Study: Incremental Cost-effectiveness Ratio of ICD Compared With Conventional Therapy**

<table>
<thead>
<tr>
<th></th>
<th>Conventional Therapy</th>
<th>ICD</th>
<th>Difference</th>
<th>95% CI*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net present value of total costs†</td>
<td>75.98</td>
<td>97.56</td>
<td>21.58</td>
<td>0.1 to 43.1</td>
</tr>
<tr>
<td>Expected survival†</td>
<td>2.66</td>
<td>3.46</td>
<td>0.80</td>
<td>0.41 to 1.22</td>
</tr>
<tr>
<td>iCER†</td>
<td>27.0</td>
<td></td>
<td></td>
<td>0.2 to 68.2</td>
</tr>
</tbody>
</table>

iCER indicates incremental cost-effectiveness ratio.

*Bootstrap-based CI for differences and for iCER.
†In 4 years (in thousands of dollars and in years, respectively, discounted at 3% per annum).
‡In thousands of dollars per year-of-life saved (within 4 years); iCER = ratio of differences, line 1/line 2.
evaluate the effect of the cost of the devices themselves, we require replacement within 4 years would drop the incremental cost-effectiveness ratio to $12,500 per life-year. To assess variability in the incremental cost-effectiveness ratio (iCER), each point represents a reestimation of the difference in total costs (net present value of accumulated costs) and the corresponding years of life saved, all within 4 years. The ratio is the corresponding iCER. The study data yielded an actual iCER of $27,000 per life-year. A bootstrap-based 95% CI for the iCER is $200 to $68,200 per life-year, indicated by the dashed lines.

The variability surrounding this estimate is illustrated in Figure 3, derived from bootstrap replications. The solid line goes from the origin to the point representing the differences in costs and survival that we actually found; its slope (27.0) represents the incremental cost-effectiveness ratio. This line thereby depicts a set of points associated with an incremental cost-effectiveness ratio of $27,000 per life-year. The points below this line would have a lower (i.e., more favorable) incremental cost-effectiveness ratio, while those above the line represent less-favorable estimations of cost-effectiveness. Although the majority (89%) of the points are < $50,000 per life year (represented by the dashed line), a value frequently used to judge cost-effectiveness, some are above this line. The 95% confidence limits based on this analysis range from a low of $200 to a high of $68,200 per life-year saved (Table 4).

Sensitivity Analyses
We explored ways to represent present-day technologies and to assess variability in the incremental cost-effectiveness ratio according to methodological issues and limitations of our study. (See Table 5.)

During the study, defibrillator costs ranged from $18,500 to $27,400. The average cost for a transvenous device was $22,800 higher than for a transthoracic system. The initial costs for patients receiving a transvenous device were lower, however, by $8,800 on average. If one eliminates this difference of $6,600, the incremental cost-effectiveness ratio drops from $27,000 per life year to $22,800 per life year ($18,000/0.80 = $22,800). Eighteen patients required a replacement generator during the trial, primarily in year 4. An assumption that modern devices with more generator capacity should not require replacement within 4 years would drop the incremental cost-effectiveness ratio to $12,500 per life year. To evaluate the effect of the cost of the devices themselves, we reduced these by 25% and by 50%, lowering the incremental cost-effectiveness ratio to $13,100 or $33,000 per life-year saved, respectively.

Four patients received either a heart transplantation or renal dialysis during the study. All four were in the conventional therapy group. Before identifying that all were in the conventional therapy group, we reviewed the study records on each of these patients to establish whether it was likely that the transplantation or dialysis was related to the experimental intervention (either ICD or conventional treatment) or could have been prevented by it. Because in each case this seemed unlikely, we reduced these hospital costs to a maximum of $40,000, a cost that would be expected with a complex hospitalization but not a transplant or dialysis. Next, we eliminated these four patients completely and repeated the analysis without them. The first adjustment had only a modest effect on the incremental cost-effectiveness ratio, moving it from $27,000 to $32,900 per life-year. The second adjustment increased the incremental cost-effectiveness ratio to $39,600 per life-year.

Some individuals crossed over from ICD to conventional therapy and vice versa. We dropped the 11 conventional therapy patients who received an ICD subsequently and reassigned to the conventional therapy group the 4 patients who were assigned to an ICD but refused one. This resulted in an estimated incremental cost-effectiveness ratio of $32,900 per life-year saved. The statistical effect of the sequential stopping rule used in MADIT\textsuperscript{c} could lead to biases in secondary survival analyses, in particular to possible overestimation of years of life saved, and in contrast to the primary survival-benefit analysis,\textsuperscript{d} no formal adjustment methods are available. However, on the basis of an analysis not detailed here, we estimated that the years of life saved may need to be reduced by 21% and the differential costs (which are also affected by survival) by 14%. The resulting cost-effectiveness ratio is not markedly different, namely, $29,300 instead of $27,000 per life-year, an increase of 8.5%. This also serves as a basis for a

### Table 5. MADIT Cost-effectiveness Study: Sensitivity of iCERs to Technologies and Methods

<table>
<thead>
<tr>
<th>Technology Changes</th>
<th>iCER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic results (base case)</td>
<td>$27,000/LY</td>
</tr>
<tr>
<td>Technology changes</td>
<td></td>
</tr>
<tr>
<td>TV device used</td>
<td>$22,800/LY</td>
</tr>
<tr>
<td>Replacement generator &gt;4 years</td>
<td></td>
</tr>
<tr>
<td>TV device used and cost reduced 25%</td>
<td>$12,500/LY</td>
</tr>
<tr>
<td>TV device used and cost reduced 50%</td>
<td>$13,100/LY</td>
</tr>
<tr>
<td>TV device used and cost reduced 50%</td>
<td>$33,000/LY</td>
</tr>
<tr>
<td>Methodological issues</td>
<td></td>
</tr>
<tr>
<td>Reduce $ for transplant/dialysis patients</td>
<td>$32,900/LY</td>
</tr>
<tr>
<td>Drop transplant/dialysis patients</td>
<td>$39,600/LY</td>
</tr>
<tr>
<td>Analysis without crossovers</td>
<td>$32,900/LY</td>
</tr>
<tr>
<td>Correction for sequential stopping rule</td>
<td>$29,300/LY</td>
</tr>
<tr>
<td>Extrapolation from 4 to 8 years</td>
<td>$16,900/LY</td>
</tr>
</tbody>
</table>

iCER indicates incremental cost-effectiveness ratio; LY, life-year saved; and TV, transvenous.

ICD compared with conventional management.
sensitivity analysis of the ICD effectiveness. Another reduc-
tion of 21% in effectiveness would yield another 8.5% increase in the incremental cost-effectiveness ratio to $32 000 per life-year.

Our study lasted 5 years, and reliable information on which to base cost-effectiveness calculations was limited to 48 months. To evaluate the economic consequences more closely resembling a lifetime strategy, we fit Weibull survival curves\textsuperscript{14} to the survival data and extrapolated beyond the 4-year Kaplan-Meier curves. Assuming that costs would remain on average $1915 per month for conventional therapy and $1394 per month for ICD in surviving patients (extrapolating from Figure 1 and Table 3), the cost-effectiveness ratio would fall to $16 900 per life-year in 8 years ($34 200/2.02=$16 900).

**Discussion**

Our analyses indicate that when an ICD is used for the prevention of sudden death in selected high-risk patients, this therapeutic strategy is cost-effective. These conclusions are, of course, limited to the clinical circumstances and the patient characteristics actually included in the trial from which these data are derived. Whether this technology would be as cost-effective when used otherwise is an important question and one for which we can provide only limited insights. In individuals with a lower probability of fatal arrhythmias, in whom there is less potential for benefit, the cost-effectiveness would be expected to be less favorable.\textsuperscript{15}

The adequacy and completeness of the information collected in this study also limit our conclusions. We relied principally on patient self-reports of health care use prompted by regular and systematic follow-up by nurse clinical coordinators. Although we were successful in achieving almost complete data collection for the economic parameters of interest, it is impossible to be fully confident that there were no reporting errors, which could have either overstated or understated the costs. We used the best presently available methods to convert charges to costs, but these approaches are imperfect and rely on accounting procedures such as cost-to-charge ratios and Medicare cost-reimbursement schedules. We also used an indirect method for including the professional (physician and surgeon) costs by relying on a national study of DRGs based on Medicare databases. Still, hospital costs dominated, self-reporting of hospitalizations should be reliable, and our billing information was 98% complete.

The trial itself was designed and powered to detect a difference in mortality, not to obtain statistically stable estimates of a cost-effectiveness ratio. The size of the population available to us for analysis and the variability in the costs of care results in fairly wide confidence limits around these estimations. Larger studies that include data collection for effectiveness evaluation will advance such assessments.

This study took place during the technical evolution of the ICD. In fact, our results represent a mixture of an old (transthoracic placement and single-purpose defibrillators) and a relatively new (transvenous multipurpose devices) technology. We explored what the effect of these changes might be on the resulting cost-effectiveness ratios by simulating the changes that would occur if all defibrillators had been placed transvenously, the costs of placing the devices had been lower, and generators had lasted longer before replacement. We therefore can estimate only indirectly the cost-effectiveness of treatment with present-day technology.

Information about the cost-effectiveness of the ICD has been limited by the scarcity of studies that have addressed this issue and by the methods previously used for economic assessment.\textsuperscript{16–23} This study, an integral part of the randomized trial to test the effectiveness of ICD management, provides the most direct evidence available concerning the cost-effectiveness of this technology. Despite its high initial costs, ICD therapy in selected individuals appears to be cost-effective. Although there is not yet widespread agreement about the value (ie, cost per life-year saved) that a new technology must achieve, our estimate is clearly within the range considered acceptable and routine within our healthcare system.\textsuperscript{24}

The overall cost implications of adding this technology to present-day spending are important to consider as well. Extrapolating our results to 8 years, together with use of transvenous devices with a modest reduction in cost (<25%), the estimated incremental cost-effectiveness ratio would be $10 000 per life-year (combining effects shown in Table 5). With estimated average savings of 2 years of life (the 8-year span projection), the lifetime cost increase would be roughly $20 000 per patient. If one uses a current estimate of 16 000 individuals in the United States annually meeting the MADIT entry criteria\textsuperscript{25} and assumes each is offered an ICD, the steady-state annual extra cost would be roughly $320 million for 32 000 years of life saved annually. Both effects, the additional years of life and the costs, must be kept in mind and compared with other options for healthcare spending to inform health policy.\textsuperscript{24} The device would be even more attractive economically if its cost were lower and the generator replacement time longer.

The most important challenge for both clinical practice and healthcare policy, however, remains the more definitive definition of the clinical characteristics used to select patients for this new technology versus current alternatives so as to prevent both its overuse and its underuse. In the future, such decisions will increasingly depend on the economic as well as the survival implications for these individuals.

**Appendix**

The following investigators participated in the Multicenter Automatic Defibrillator Implantation Trial: D. Cannom, Good Samaritan Hospital, Los Angeles, Calif; J. Daubert, University of Rochester, Rochester, NY; S. Higgins, Scripps Memorial Hospital, La Jolla, Calif; H. Klein, University Hospital, Magdeburg, Germany; J. Levine, Saint Francis Hospital—Heart Center, Roslyn, NY; S. Saksena, Eastern Heart Institute, Passaic, NJ; A. Waldo, Case Western Reserve University and University Hospitals of Cleveland, Cleveland, Ohio; D. Wilber, University of Chicago, Chicago, Ill; S. Sridhar, Affiliated Cardiologist, Phoenix, Ariz; T. Mattioni, Arizona Heart Institute and Foundation, Phoenix; J. Maloney and B. Wilkoff, Cleveland Clinic Hospital, Cleveland, Ohio; R. Krol, Eastern Heart Institute, Passaic, NJ; A. Leon, Emory Clinic, Atlanta, Ga; R. Cierpka and H.-J. Trappe, Hanover Medical School, Hanover, Germany; S. Kutalek, Hahnemann University Hospital, Philadelphia, Pa; J. Rottman, Jewish Hospital of St. Louis, St. Louis, Mo; T. Gruenier and G. Tomasselli, Johns Hopkins University Hospital, Baltimore, Md; B. Olshansky, Loyola University Medical Center, Chicago, Ill; J. Daubert, B. Olshansky, J. Rottman, T. Gruenier, G. Tomasselli, D. Cannom, J. Maloney, B. Wilkoff, R. Krol. The following institutions participated in the MADIT follow-up study: Cleveland Clinic Hospital, Cleveland, Ohio; B. Olshansky, Loyola University Medical Center, Chicago, Ill; J. Daubert, B. Wilkoff, R. Krol. The following computers participated in the MADIT follow-up study: D. Cannom, Good Samaritan Hospital, Los Angeles, Calif; J. Daubert, University of Rochester, Rochester, NY; S. Higgins, Scripps Memorial Hospital, La Jolla, Calif; H. Klein, University Hospital, Magdeburg, Germany; J. Levine, Saint Francis Hospital—Heart Center, Roslyn, NY; S. Saksena, Eastern Heart Institute, Passaic, NJ; A. Waldo, Case Western Reserve University and University Hospitals of Cleveland, Cleveland, Ohio; D. Wilber, University of Chicago, Chicago, Ill; S. Sridhar, Affiliated Cardiologist, Phoenix, Ariz; T. Mattioni, Arizona Heart Institute and Foundation, Phoenix; J. Maloney and B. Wilkoff, Cleveland Clinic Hospital, Cleveland, Ohio; R. Krol, Eastern Heart Institute, Passaic, NJ; A. Leon, Emory Clinic, Atlanta, Ga; R. Cierpka and H.-J. Trappe, Hanover Medical School, Hanover, Germany; S. Kutalek, Hahnemann University Hospital, Philadelphia, Pa; J. Rottman, Jewish Hospital of St. Louis, St. Louis, Mo; T. Gruenier and G. Tomasselli, Johns Hopkins University Hospital, Baltimore, Md; B. Olshansky, Loyola University Medical Center, Chicago, Ill; J. Daubert, B. Olshansky, J. Rottman, T. Gruenier, G. Tomasselli, D. Cannom, J. Maloney, B. Wilkoff, R. Krol.
Maywood, Ill; J. Salerno, Matteo Hospital, Pavia, Italy; B. Crevey, Methodist Hospital, Indianapolis, Ind; C. Pratt and D. Zhu, Methodist Hospital, Houston, Tex; M. Pitzker, Minneapolis Heart Institute, Minneapolis, Minn; S. Winters, Morristown Memorial Hospital, Chicago, Ill; F. Abi-Samra, Ochsner Clinic, New Orleans, La; B. Hallperin, J. Kron, and J. McNamulty, Oregon Health Sciences University, Portland; J. Steinberg, Roosevelt-St. Luke’s Medical Center, New York, NY; S. Greenberg and D. Hoch, St. Francis Hospital–Heart Center, Roslyn, NY; J. Gallagher, Sanger Clinic–Carolina Heart Institute, Charlotte, NC; J. Ilvento, Santa Barbara Cottage Hospital, Santa Barbara, Calif; R. Winkle, Sequoia Hospital, Palo Alto, Calif; M. Lechmann, Sinai Hospital, Detroit, Mich; M. Scheinman, University of California Medical Center, San Francisco; R. Myerburg, University of Miami Medical Center, Miami, Fla; T. Akiyama and W. Zareba, University of Rochester Medical Center, Rochester, NY; R. Ruffy, University of Utah School of Medicine, Salt Lake City; and E. Platia, Washington Hospital Center, Washington, DC.


Statistical support: M. Heo and Ban Chuan Cheah.

Acknowledgments
The study was supported by an independent research grant to the University of Rochester from CPI/Guidant Corporation, St. Paul, Minn. We are indebted to the patients who participated in this trial; to the attending physicians who referred their patients to this study; and to CPI/Guidant Corporation for its support and sustained commitment, for supplying the defibrillators, and for the independence it provided to the investigators to conduct the study. The data collection for this study was greatly facilitated by the cooperation of the MADIT Coordination and Data Center under the direction of Mary W. Brown, MS.

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Alvin I. Mushlin, W. Jackson Hall, Jack Zwanziger, Elizabeth Gajary, Mark Andrews, Rebecca Marron, Kelly H. Zou and Arthur J. Moss
for the MADIT Investigators

Circulation. 1998;97:2129-2135
doi: 10.1161/01.CIR.97.21.2129

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/97/21/2129

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