Implantable cardioverter-defibrillators (ICDs) are one of the few interventions where we can be reasonably confident that a patient did or did not benefit from the treatment. If one is to benefit from an ICD, then the person must survive long enough to have an arrhythmic event and receive therapy from the device. Thus, the patients who benefit the most are those with a high rate of arrhythmic death and a low rate of nonarrhythmic death. Indeed the enrollment criteria for clinical trials of ICDs were designed to optimize these 2 rates. Accordingly, the patients enrolled in the primary prevention ICD trials were much younger and had less comorbidity than the community heart failure population.1

On the basis of trial results, we now have guidelines for ICDs that limit them to patients with an ejection fraction below 35% if symptomatic (New York Heart Association Class II or III) or <30% if asymptomatic (New York Heart Association Class I) and expected survival of at least one year.2 However, the clinician is frequently confronted with a patient who meets the primary prevention ICD criteria yet has other characteristics (advanced age or multiple comorbidities) that create legitimate concern that the patient will not benefit from the device. Payers, policy makers, and society warn that even if there is a benefit in these patients, it may be too small to justify the cost. In other words, they question whether an ICD has value in the elderly and those with multiple comorbidities. Although no threshold for value has been widely accepted, many consider a cost per life year (or quality-adjusted life year) gained below $50 000 to $100 000 to be cost-effective. Past economics (advanced age or multiple comorbidities) that create legitimate concern that the patient will not benefit from the device. Thus, the patients who benefit the most are those with a high rate of arrhythmic death and a low rate of nonarrhythmic death. Indeed the enrollment criteria for clinical trials of ICDs were designed to optimize these 2 rates. Accordingly, the patients enrolled in the primary prevention ICD trials were much younger and had less comorbidity than the community heart failure population.1

What about the patients in the community not represented in these trials? The question of ICD value in older patients those with multiple comorbidities was addressed by Chan et al3 in this issue. Although it would have been ideal to enroll large numbers of the very elderly and those with multiple comorbidities in clinical trials, that has not occurred and is unlikely to happen in the foreseeable future. Thus, Chan et al relied on a registry of patients who were candidates for primary prevention with an ICD. Although these patients had to provide informed consent which may have limited the population to a somewhat healthier cohort, the investigators were able to evaluate the association of ICD placement and survival for a large number of elderly patients and those with comorbidities. They found that as age increased the absolute benefit of an ICD in terms of life-years gained increased with their top age category being 75 years or higher. Thus, implanting an ICD in those at least 75 years of age was a better value than implanting one in those younger than 65. As comorbidities increased the value of implanting an ICD decreased but was still acceptable if we assume society is willing to pay at least $50 000 to gain 1 year of life. The findings by Chan et al confirm a MADIT-II substudy of the elderly where the hazard ratio for mortality with an ICD (0.56) for those 75 years of age and higher was slightly better than the hazard ratio (0.63) for those less than 75 years.5

If patients in their upper 70s are good candidates for ICDs, where is the limit? Is anyone too old for an ICD? The article by Chan et al enrolled few patients 80 years and older to make precise estimates. However, we can use prior studies and models of outcome to get at the answer. A prior model of ICD outcome by Sanders et al3 based on clinical trials was used to determine how the different rates of arrhythmic and nonarrhythmic death impact the value (cost-effectiveness) of an ICD.6 This is shown graphically in the Figure.

We can see from the Figure that one can be too healthy for an ICD. If the annual risk of death is less than 5%, then an ICD is very expensive for the gain in benefit (ie, not worth it). If total mortality is at least 5% per year, we then examine the ratio of arrhythmic to nonarrhythmic mortality. We see that if this ratio is at least 50:50 then ICDs have value even at extremely high mortality rates. Indeed, the model indicates that among patients with an expected median survival of less than 1 year (median 1 year mortality >50% and currently excluded from receiving an ICD by guidelines) an ICD would still be of value if arrhythmic deaths were at least as likely as nonarrhythmic deaths.

But how can we predict who will and will not have an arrhythmic death? A recent study examined the relationship between arrhythmic death rate and age.7 Using an analysis of clinical trials of patients with heart failure or myocardial infarction Krahn found that arrhythmic and nonarrhythmic death rate both increase in absolute terms as one ages, with nonarrhythmic death rates increasing faster (Table). Using the Figure, we can estimate cost-effectiveness for the different age groups. First, we see that these estimates of value show a similar pattern to those by Chan et al. Both models agree that

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From the Veterans Affairs Palo Alto Health Care System (P.H.), Palo Alto, Calif; and the Stanford University School of Medicine (P.H., V.T.), Stanford, Calif.

Correspondence to Paul Heidenreich, MD, MS, 111C Cardiology, VA Palo Alto Health Care System, 3801 Miranda Ave, Palo Alto, CA 94304. E-mail heiden@stanford.edu


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ICDs for patients in their 70s appears to be a reasonable value, though we project that beyond 80 years of age that is less likely to be the case. Most of these patients in the >80 years group from the Krahn analysis (Table) were in their early 80s, and the value of an ICD in those 85 years and higher is likely to be much smaller.

Although age is clearly important, including other variables such as comorbidities may improve the estimates of arrhythmic death. The Seattle Heart Failure Model is a validated prediction tool of total mortality using clinical, laboratory, medication, and device variables. The model was used to predict cause of death (arrhythmic and pump failure or other) in a cohort of over 10 000 patients with heart failure from 6 clinical trials (Table). One year mortality for those with a score of 0 was less than 5% so ICDs are unlikely to be of value in these patients. Similarly, the ICDs do not appear to be a good value in the sickest patients who have a relative low rate of arrhythmic death compared to nonarrhythmic death.

The purpose of this exercise was to show the importance of both total mortality and the ratio of arrhythmic to nonarrhythmic death in determining the value of an ICD. The estimates of cost-effectiveness for an individual patient will depend on many factors not considered here including preference for length and quality of life which has been show to be highly variable and often changes markedly following an acute episode of heart failure.

What can we conclude from this? First, it is not simple to predict the relative rates of arrhythmic and nonarrhythmic causes of death with currently available data. Perhaps future markers will help. Second, as patients with heart failure age the increase in total mortality is somewhat offset by a slower increase in arrhythmic death rate making the

### Table. Mortality and Cause of Death Estimates Using Different Patient Groups and the Impact on Cost-Effectiveness of ICDs

<table>
<thead>
<tr>
<th>Patient Group</th>
<th>Total Annual Mortality</th>
<th>Arrhythmic/Nonarrhythmic Ratio</th>
<th>Cost-Effectiveness, $/Quality-Adjusted Life Year*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years†</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;50</td>
<td>11</td>
<td>1.1</td>
<td>$55 000</td>
</tr>
<tr>
<td>51–60</td>
<td>13</td>
<td>0.9</td>
<td>$60 000</td>
</tr>
<tr>
<td>61–70</td>
<td>18</td>
<td>0.65</td>
<td>$65 000</td>
</tr>
<tr>
<td>71–80</td>
<td>22</td>
<td>0.65</td>
<td>$65 000</td>
</tr>
<tr>
<td>&gt;80</td>
<td>25</td>
<td>0.34</td>
<td>$85 000</td>
</tr>
<tr>
<td>Seattle Heart Failure Model score‡</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 (healthiest 38%)</td>
<td>4</td>
<td>4</td>
<td>$100 000</td>
</tr>
<tr>
<td>1 (41% of patients)</td>
<td>11</td>
<td>1.3</td>
<td>$50 000</td>
</tr>
<tr>
<td>2 (16% of patients)</td>
<td>24</td>
<td>0.72</td>
<td>$60 000</td>
</tr>
<tr>
<td>3 (3% of patients)</td>
<td>55</td>
<td>0.67</td>
<td>$85 000</td>
</tr>
<tr>
<td>4 (sickest 0.5%)</td>
<td>82</td>
<td>0.46</td>
<td>&gt;$150 000</td>
</tr>
</tbody>
</table>

*Cost effectiveness estimates from the Figure adapted from Am Heart J. 2002;144:440–448.
†Adapted from Am Heart J. 2004;147:837–840.
‡Adapted from Circulation. 2007;116:392–398.
cost-effectiveness of ICDs relatively stable until patients are into their mid 80s. Is there an age limit beyond which there is poor value from an ICD? Yes, but we will need additional well-designed outcome studies like Chan’s to determine what age this might be and to fill in the many other knowledge gaps not addressed by clinical trials.

Disclosures
Dr. Heidenreich has the following potential conflict of interest: Consultant to the ALTITUDE Clinical Science Initiative, Sponsored by Boston Scientific, less than $5000.

References

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Paul A. Heidenreich and Vivian Tsai

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