A Convenient Approximation of Life Expectancy
(The "DEALE")

II. Use in Medical Decision-Making

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We show how to use a bedside approximation of life expectancy in quantitative decision-making. This method, the declining exponential approximation of life expectancy (DEALE), enables the physician to collate various survival data with information on morbidity to determine a quality-adjusted expected survival for a potential management plan. The keystone in the DEALE approach is the approximation of survival by a simple exponential function. This approximation makes it possible to translate data from various literature sources (life expectancy tables, five-year survival rates, survival curves, median survival) into a single, unified mortality scale. In this paper, we use the DEALE method to obtain approximations of quality-adjusted life expectancy and illustrate the application of the method in a quantitative analysis of a clinical decision.

Medical outcomes have a multitude of attributes (length of survival, physical discomfort, psychological burden, expense), yet these attributes cannot be easily combined, ordered, and compared on a single convenient scale. For this reason, it is difficult to select among several possible therapeutic approaches when they can result in outcomes with quite different characteristics. When choosing among therapies, the practitioner often makes "rough and ready" value judgments that collapse all possible outcomes into a single, intuitive scale [1].

Decision analysis, a powerful tool for the modeling of clinical problems, is limited by similar constraints. In this method, health effects of medical decisions are represented as utilities. Many decision analysts have used an arbitrary utility scale (e.g., 0 to 100) to quantify outcomes [2-4]. When such scales are employed, small differences in expected utility can pose a problem: is the calculated benefit of one choice over another "significant" in light of other factors important to the patient but not explicitly considered in the analysis? Some investigators have addressed this issue by constructing complicated functions relating mortality and morbidity [5]; such functions are often too cumbersome for the practicing physician, who requires a simpler method of assessing expected utility [6].

Because medicine has failed to develop a standard method for dealing with diverse survival data, each clinical specialty has adopted its own framework for reporting survival and health status. Surgeons typically report "operative mortality rates"; oncologists report "five-year survival rates"; others show results as survival curves. Although these methods are sometimes consistent in the literature...
concerning a single disease, the data cannot be combined and used in prospective decision-making when the patient is at risk from two or more diseases or complications.

Many decisions assessed by decision analysis require measures of mortality and morbidity. Recognizing the need for a consistent scale, we developed an approximation of life expectancy that can incorporate survival and health status data from diverse sources. We simplify the problem of integrating such data by using a declining exponential approximation for calculating life expectancy (the "DEALE") (Part I, p 883, this issue). This method reduces calculations of life expectancy to simple arithmetical manipulations available to all physicians. In this paper, we use the DEALE approach to unify diverse survival and morbidity data, and we illustrate its application in decision analysis.

METHODS

Definition of the Problem. For the method presented herein to be applicable, the focus of the decision must involve life expectancy and quality of life; that is, the various alternative management plans must yield different durations and qualities of survival. The assessment of the relative worth of outcome states is common to all clinical decision-making. However, the benefit of the DEALE are best understood in the decision analytic formalism. Although we shall not provide a general introduction to decision theory here, we briefly summarize the process to provide the proper context. First, the problem is structured, typically as a decision tree. Second, a probability is assigned to each chance event. Third, each potential outcome is assigned a relative value or utility, employing a single consistent scale. (The DEALE is used in the process of utility assessment.) Fourth, the average or expected utility of each strategy is calculated, and the strategy with the highest expected utility is deemed "best." Finally, the impact of various assumptions and soft data are examined through sensitivity analysis. We show how a problem focused exclusively on the quantity and quality of life is explored using the DEALE as a method of outcome valuation.

Brief Summary of the DEALE Method. To obtain a quality-adjusted life expectancy value for a given patient outcome, these steps are followed: (1) Take the reciprocal of the patient's age-, sex-, and race-adjusted life expectancy (obtained from a table of vital statistics) to obtain the age-, sex-, and race-adjusted average mortality rate ($\mu_{ASR}$). (2) Obtain the disease-specific mortality rates for all competing independent diseases ($\mu_{D1}$, $\mu_{D2}$, ...) by one or more of the methods to be described. (3) Take the reciprocal of the sum of $\mu_{ASR}$ and all values for $\mu_D (1/\mu_{ASR} + \mu_{D1} + \mu_{D2} + ...)$ to obtain life expectancy. (4) Adjust life expectancy for short-term and/or long-term morbidity as illustrated later in this article to obtain quality-adjusted life expectancy.

Anchor Points. In assessing outcomes for a clinical problem, we first establish two boundaries or anchor points—the best and the worst possible survival for the patient, according to age, sex, and race. A convenient "best outcome" is the age-, sex-, and race-adjusted life expectancy ($LE_{ASR}$), in which life expectancy is defined as the mean duration of survival for a cohort of similar people [7]. Tables of vital statistics containing such data are readily available [8]. Although "normal" life expectancy is unattainable for many patients because underlying disease shortens survival, this upper bound nevertheless provides a useful and easily obtained anchor point. Immediate death establishes a convenient "worst outcome," a life expectancy of zero. This anchor point is an important lower bound even if "immediate death" is not one of the possible consequences under consideration. It should be noted, of course, that the relative difference in life expectancies among treatment options establishes the preferred clinical decision.

Next, the life expectancy that defines the upper anchor point ($LE_{ASR}$) is converted into a baseline average mortality rate. The assumptions underlying this approximation and the validation of this approximation are described in Part I, p 883, this issue. The calculation is made by taking the reciprocal of the age-, sex-, and race-adjusted life expectancy to obtain the baseline mortality rate $\mu_{ASR}$:

$$\mu_{ASR} = 1/LE_{ASR}$$

For example, the average annual mortality rate of a healthy 67 year old white man with a life expectancy of 13.5 years is $1/13.5$, or 0.074 per year.

Determination of Intermediate Life Expectancies. If a medical management problem has only two possible outcomes, immediate death and full population life expectancy, the previous anchor points are sufficient. Of course such situations are uncommon; usually there are competing causes of death, outcomes with intermediate survivals, and short- and long-term morbidities, all of which must enter into the valuation of outcome states. We now explain how to incorporate intermediate life expectancies in the utility structure.

Competing causes of death (from the presence of one or more diseases or complications) are expressed as average mortality rates in a fashion similar to that done for the upper anchor point. The effects of such additional risks are approximated by adding the excess mortality rate for each cause ($\mu_D$) to the baseline rate ($\mu_{ASR}$) (see Part I, p 883, this issue). This process is equivalent to adding exponents, that is, multiplying the probabilities of survival.

Calculation of disease-specific excess mortality rate: Because most studies in the literature report the overall or compound survival of a cohort of patients with a given disease, the baseline mortality (based on age, sex, and race) of the population studied must be corrected for. Thus, each disease-specific excess mortality rate ($\mu_D$) is calculated by subtracting a population mortality rate specific to a study report (denoted $\mu_{pop}$, in which "pop" reflects demographic characteristics—age, sex, and race—of the studied disease population) from the compound mortality rate derived from the study in the literature ($\mu_c$):

$$\mu_D = \mu_c - \mu_{pop}$$

Following are descriptions of mortality data commonly found in literature studies, with illustrations of the techniques required to convert them into excess annual mortality rates. We consider five classes of data: mortality rates, life expectancy,
Mortality rates may be used directly, provided that they are not compound. Unfortunately, excess mortality rates are rarely reported. When they are, they are described as follows: "With disease D the additional risk of death is x/1,000 per year." The reference manual by Singer and Levinson [9], for example, provides the excess mortality rates of many diseases.

If a reported mortality rate is a compound value, it must be adjusted for the population base mortality rate. This latter value must correspond to the study population and not to the patient under consideration. To illustrate: assume the compound annual mortality rate \( \mu_c \) of a group of males of average age 56 with disease D is 0.230 per year. To calculate the disease-specific excess mortality rate \( \mu_0 \):

1. Determine that the life expectancy of 56 year old males is 19.7 years from a table of vital statistics [8].
2. Take the reciprocal of life expectancy to obtain the approximate population base rate for a 56 year old male: \( \mu_{pop} = 1/19.7 = 0.051 \) per year.
3. Subtract the study population base rate \( \mu_{pop} \) from the compound mortality rate \( \mu_c \) (equation 2) to arrive at the excess disease-specific mortality rate \( \mu_0 \): \( 0.230 - 0.051 = 0.179 \) per year (Table I, example 1).

Life expectancies are examples of compound mortalities, usually described as follows: "With disease D the life expectancy was x years." In order to obtain excess mortality rate from a reported life expectancy, the reciprocal of life expectancy (i.e., the average yearly compound mortality rate) must be compared with a study population mortality rate. For example, assume that the life expectancy of a group of patients (both sexes, average age 55), with disease D is 4.5 years (a compound life expectancy). To calculate the disease-specific mortality rate, the mortality rate for healthy 55 year olds must be used:

1. Determine that the life expectancy, age 55 (both sexes), is 23.1 years from a table of vital statistics [8].
2. Take the reciprocal to obtain the population base rate for a 55 year old: \( \mu_{pop} = 1/23.1 = 0.043 \) per year.
3. Take the reciprocal of compound life expectancy for 55 year old patients with the disease to obtain the compound mortality rate: \( \mu_c = 1/4.5 = 0.222 \) per year.
4. Subtract \( \mu_{pop} \) from \( \mu_c \) to arrive at the disease-specific excess mortality rate (equation 2): \( \mu_0 = 0.222 - 0.043 = 0.179 \) per year (Table I, example 2).

Five-year survivals and other single-point survival data (two-year, 10-year, etc.) are converted into mortality rates by a logarithmic transformation. Such survival data are probabilities. Statements such as "five-year survival (S) in disease D was x percent" can be interpreted as "the probability of surviving five years with D was x/100." The average annual rate can be calculated using the equation:

\[
\bar{\mu} = -\frac{1}{t} \ln(S)
\]

in which the probability is substituted for S and the number of years is substituted for t. In general, this transformation yields a compound mortality rate. The disease-specific excess mortality rate is then calculated as before using equation 2.

For example, if the five-year survival of a group of patients (both sexes, average age 55) with disease D is 20 percent, then the disease-specific mortality rate \( \mu_0 \) would be calculated as follows:

1. Steps 1 and 2. Obtain \( \mu_{pop} \) for 55 year old persons, as described in the second example: \( 1/23.1 = 0.043 \) per year.
2. Step 3. Obtain compound mortality rate using equation 3:
   \[\mu_c = -1/5 \ln(0.20) = 0.322 \text{ per year.}\]
3. Step 4. Apply equation 2; \( \mu_0 = 0.322 - 0.043 = 0.279 \) per year (Table I, example 3).

Median survivals are defined as the time at which half of the population under study has died. A statement such as "median survival in disease D was x years" is equivalent to "the probability of surviving x years with D was 0.5." Thus, equation 3 may be used, with 0.5 substituted for S and the survival time for \( t \) in the equation. Of course, this is equivalent to:

\[
\bar{\mu} = 0.693/t
\]

For example, let us assume that the median survival of a

**TABLE I**

Examples of Excess Mortality Rates Calculated from Various Sources

<table>
<thead>
<tr>
<th>Example</th>
<th>Source</th>
<th>Study Population</th>
<th>Reported Data</th>
<th>Estimated Mortality Rates (per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Compound Rate (( \mu_c ))</td>
</tr>
<tr>
<td>1</td>
<td>Mortality rate</td>
<td>56 year old men</td>
<td>0.230 per year</td>
<td>0.230</td>
</tr>
<tr>
<td>2</td>
<td>Life expectancy</td>
<td>55 year old men</td>
<td>4.5 years</td>
<td>0.222</td>
</tr>
<tr>
<td>3</td>
<td>Five-year survival</td>
<td>55 year old men</td>
<td>20%</td>
<td>0.322</td>
</tr>
<tr>
<td>4</td>
<td>Median survival</td>
<td>56 year old men</td>
<td>3.2 years</td>
<td>0.217</td>
</tr>
<tr>
<td>5</td>
<td>Survival curve</td>
<td>56 year old men</td>
<td>Curve (Figure 1)</td>
<td>0.241</td>
</tr>
</tbody>
</table>

* \( \mu_0 = \mu_c - \mu_{pop} \); see text.

* This life expectancy is higher than the value used in the first example for 56 year old men because the study population in this example includes both sexes.
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different values of \( \mu \). A rough average rate can be obtained by selecting several points on the curve, calculating the mortality rates using equation 3, and averaging the results.*

The nature of reported survival curves must be carefully noted. The contemporary cancer literature sometimes reports corrected survival, from which the population base mortality rate already has been subtracted. If corrected survival is reported, then the mortality rates obtained from equation 3 may be used directly. Other survival curves may be examples of compound mortality; rates derived from such curves must be corrected for the characteristics of the study population as described before.

Calculation of Patient-Specific Life Expectancy Using the DEALE. Having derived the baseline average mortality rate for the patient under consideration and the excess mortality rate for each independent disease or risk factor, the clinician can then calculate the patient-specific life expectancy (PSLE) for each intermediate outcome by applying the following equation:

\[
PSLE = \frac{1}{\mu_{A} + \mu_{D1} + \mu_{D2} + \cdots}
\]

For example, let us consider a 45 year old man whose life expectancy based on his age, sex, and race is 27.8 years [8]. His age-, sex-, and race-adjusted mortality rate \( \mu_{A} \) is 0.036 per year. If that man were suffering from the disease in the first example described earlier, producing an excess mortality of 0.179 per year, then his overall mortality rate would be 0.036 + 0.179 or 0.215 per year, and his life expectancy would be 1/0.215 or 4.7 years. Conversely, if he were suffering from the disease in the third example described before, producing an excess mortality of 0.279 per year, then his overall mortality rate would be 0.315 per year, and his life expectancy would be 1/0.315 or 3.2 years. Finally, if he were suffering from both diseases shown in the first and third examples, then his overall mortality rate would be 0.036 + 0.179 + 0.279, or 0.494 per year; his life expectancy would be 1/0.494, or 2.0 years.

Quality Adjustments of Life Expectancy. The life expectancies calculated for each outcome can be adjusted for variations in the quality of life. Recently, subjective benefits and modifications of health status have been assessed by the use of weighting functions [5,6,10]. We use the following simplifying approximations to address common medical complications:

**Short-term morbidity** (for example, perioperative pain) is subtracted from calculated life expectancy. Any life expectancy associated with temporary discomfort or disability is reduced by an amount that reflects the quality of life lost due to morbidity. In most cases, the loss is only a few weeks or months.

**Long-term morbidity** (for example, a perioperative major stroke) is multiplied by the calculated life expectancy, that is, each of the patient's remaining years of life is reduced by a constant fraction. Thus, permanent disability is a multiplier that ranges between 0 (equivalent to death) and 1 (no disability). For example, assume that a certain complication is

\* If the survival curve is vastly different from a declining exponential, then the area beneath the curve can be planimetered. That area is equivalent to the life expectancy, and its reciprocal is \( \mu \).
permanently disabling and that the quality of life is determined to be 90 percent of full health. Suppose that the life expectancy is calculated by the DEALE approach to be 9.5 years. The quality-adjusted life expectancy would then be: 9.5 \times 0.9 \approx 8.55 \text{ years.} 

Either lottery methods or time-tradeoffs can be used to estimate the burden of temporary and permanent disability [10,11]. It must be stressed that “morbidity” includes both etiogenic and disease-related discomfort. Short-term morbidities are better visualized if deleterious effects of procedures are represented as independent risks, subject to the laws of probability, rather than the in-line “toll” assessment proposed by others [4,12]. In our approach, an adjustment is made to life expectancy only on the branch reflecting the occurrence of the untoward event, to reflect the morbidity associated with it.

CLINICAL EXAMPLE

Should Coronary Bypass Grafting Be Carried out Prior to Colectomy in a Patient with Both Coronary Disease and Colonic Cancer? A 67 year old white male recovered uneventfully from an apico-inferior myocardial infarction three years ago. Since then, he experienced no further symptoms of cardiac disease. Two months ago, in preparation for an exercise regimen, a thallium exercise stress test was performed, demonstrating significant S-T depression but no symptoms. Cardiac catheterization revealed 100 percent obstruction of the right coronary artery; 100 percent obstruction of the left circumflex coronary artery, but no significant narrowing of the left anterior descending coronary artery. The systolic ejection fraction was 60 percent. On admission to the New England Medical Center, his stool test revealed occult blood. Barium enema demonstrated an encircling lesion of the descending colon. Results of liver scan and liver function enzymes were normal. The central question was: should a coronary artery bypass be performed to decrease the operative risk during colectomy? In addition to the baseline mortality risk (age-, race-, and sex-adjusted) experienced by 67 year old men, this patient had two additional potential causes of death: severe coronary artery disease and carcinoma of the colon. We approached this problem with decision analysis, using life expectancies calculated by the DEALE approach as outcome measures.

Structure of the Problem and Probabilities. The decision tree shown in Figure 2 describes the decision: bypass first, followed by laparotomy, or immediate laparotomy without coronary artery bypass. The probabilities used in the analysis are displayed on the tree. We shall focus only on the utilities used to value the outcomes.

Utility Assessment. The upper anchor point is the life expectancy of a 67 year old healthy white male. This value, LEASR, taken from a table of vital statistics [8], is 12.6 years. Following the procedure outlined earlier, we take the reciprocal of this value, which gives an average mortality rate µASR of 0.079 per year. The lower anchor point for utility assessment, immediate death, is assigned a value of 0.

The competing risks are colon cancer and coronary artery disease. Newland and associates [13] studied a series of 503 patients with different grades and stages of colorectal carcinoma; their survival data are displayed in Figure 3 [13]. These data are corrected survival curves and therefore describe excess mortality. As an approximation, these data fit the form of a declining exponential curve. Choosing the five-year mark for survival analysis, we arrive at values for each Dukes' classification as shown in Table II*.

* Note that there are slight discrepancies between the figure and the data in their report. In this analysis, we have used the data shown in their figure (reproduced in Figure 3).
findings of a constricting lesion, this patient could not have a Dukes' stage A carcinoma. Of the lesions that are consistent with these radiologic findings, 38 percent are in stage B, 34 percent in stage C, and 28 percent in stage D (Table II) [13]. Patients with "Dukes' stage B" lesions have a five-year survival of 72 percent, corrected for underlying illness and population base mortality. Patients with "Dukes' stage C" and "Dukes' stage D" lesions have five-year survivals of 46 percent and 28 percent, respectively (also corrected). An average excess mortality rate can be calculated for the patient's currently unstaged cancer as follows:

Step 1. The average five-year survival for an unstaged cancer that may be Dukes' stage B, C, or D is calculated by multiplying each component five-year survival value by its associated probability (middle column, Table II), and then adding the products (right column). On the basis of this calculation, the expected five-year survival of a man with colon cancer of unspecified stage (but not Dukes' stage A) is 51 percent.

Step 2. This average five-year survival is converted into an average yearly mortality rate by equation 3:

\[ \mu_{\text{cancer}} = -\frac{1}{5} \ln(0.51) = 0.135. \]

Recall that the data in Figure 3 are corrected (excess) disease-specific survivals. Thus, the average yearly mortality rate for unstaged colon cancer is 0.135 per year.

The survival data in coronary artery disease are less clearly defined. In Weinstein and Stason's [14] recent summary of data from large centers and cooperative groups, the annual excess mortality rate for surgically treated patients with two-vessel coronary artery disease was 0.016 per year; the corresponding excess rate for medically treated patients was 0.024 per year. Because these figures are excess mortality rates, they can be added to the mortality rate for unstaged colon cancer without modification.

Quality adjustments to life expectancy are made to reflect the short-term morbidity of hospitalization and the long-term morbidity associated with possible perioperative myocardial infarction. We estimate the short-term effects of surgery as follows: the average time required for hospitalization and early convalescence for laparotomy is two weeks, or 0.04 years. The average time required for coronary artery bypass surgery is three weeks, or 0.06 years. If the patient has both operations, a total of 0.10 years is subtracted from calculated life expectancy to reflect the short-term morbidity associated with the operations. In effect, this technique assigns a value of 0 to time spent in the hospital and assumes restoration of a normal quality of life upon convalescence. Actually, the quality of life associated with hospitalization is not 0, but the full convalescent period extends beyond the hospital stay. We believe that equating time in the hospital to 0 is a fair approximation that, if anything, biases the analysis slightly against surgical intervention.

Perioperative myocardial infarction would somewhat prolong hospital stay but, more importantly, might cause long-term disability in terms of diminished cardiac reserve [15]. For purposes of illustration, we assumed the quality of life associated with perioperative myocardial infarction (the patient's second infarction) to be approximately 95 percent of full health. The importance of this factor was evaluated by sensitivity analysis [3,15], as will be described.

Table III summarizes all baseline mortality and morbidity values calculated using the declining exponential approximation of life expectancy method.

**Table II**

<table>
<thead>
<tr>
<th>Dukes' Classification</th>
<th>Probability of Five-year Survival</th>
<th>Fraction of Cases</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>0.72</td>
<td>0.38</td>
<td>0.27</td>
</tr>
<tr>
<td>C</td>
<td>0.46</td>
<td>0.34</td>
<td>0.16</td>
</tr>
<tr>
<td>D</td>
<td>0.28</td>
<td>0.28</td>
<td>0.08</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>0.51</td>
</tr>
</tbody>
</table>
Expectancy calculated using equation 5. The specific factors included in this calculation are shown in Table IV. Note that although the baseline life expectancy for a healthy 67 year old man is 12.6 years, the best life expectancy that this patient could expect to achieve, in view of his coronary disease and currently unstaged colonic malignancy, is 4.25 years (assuming he survives both operations without a myocardial infarction). The life expectancies for the other nonfatal outcomes range from 3.95 to 4.16 years. The expected utility of the decision to perform coronary artery bypass, calculated by "folding back" the decision tree (Figure 4), is a quality-adjusted life expectancy of 4.03 years, compared with a quality-adjusted life expectancy of 3.93 years for immediate laparotomy. Thus, the gain in life expectancy that could be expected from the surgical approach was 0.10 years, or approximately five weeks.

**Sensitivity Analysis.** For this patient, the data of particular concern were the quality adjustment for perioperative myocardial infarction and the mortality rate of laparotomy after successful coronary artery bypass. Sensitivity analysis showed that the quality adjustment for disability associated with perioperative myocardial infarction had little impact on the decision. The therapeutic option with the greater life expectancy (coronary artery surgery followed by laparotomy) also leads to fewer myocardial infarctions. A sensitivity analysis of the average annual mortality rate for surgically treated two-vessel coronary artery disease yielded a threshold or "break-even" value [16] of 0.022. Below this value, initial coronary surgery yields a greater quality-adjusted life expectancy than immediate laparotomy. Furthermore, coronary bypass surgery is preferable even if the incidence of perioperative myocardial infarction after colectomy is not decreased by coronary surgery, as long as the incidence of perioperative deaths is decreased by at least 1 percent. Of course, it should be noted that the choice is actually a close call [17].

**COMMENTS**

The declining exponential approximation of life expectancy (DEALE) is conveniently applied and sufficiently accurate to use in clinical medicine. When used in decision analysis, it has notable advantages over the arbitrary scales currently employed to assess utilities. If a utility scale had been employed with the best possible result assigned a value of 100 units and the worst possible outcome a value of 0, the result in this patient would have been something like "expected values of 94.8 units for bypass, 92.5 units for immediate laparotomy." Such numbers would be virtually impossible to interpret; the physicians caring for the patient would ponder, "What is the medical significance of a differ-

**TABLE III** Baseline Assumptions for Life Expectancy Model

<table>
<thead>
<tr>
<th>Average Mortality</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cause of mortality</td>
<td>(\mu_{\text{ASR}})</td>
<td>0.079 deaths/year</td>
</tr>
<tr>
<td>Population, age 67, white male</td>
<td>(\mu_{\text{CA}})</td>
<td>0.135 deaths/year</td>
</tr>
<tr>
<td>Colon cancer</td>
<td>(\mu_{\text{CABG}})</td>
<td>0.016 deaths/year</td>
</tr>
<tr>
<td>Two-vessel coronary artery disease</td>
<td>(\mu_{\text{MEX}})</td>
<td>0.024 deaths/year</td>
</tr>
</tbody>
</table>

**Quality Adjustments**

<table>
<thead>
<tr>
<th>Modifier</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short-term morbidity</td>
<td></td>
</tr>
<tr>
<td>Coronary bypass</td>
<td>(\text{STM}_{\text{CABG}})</td>
</tr>
<tr>
<td>Laparotomy</td>
<td>(\text{STM}_{\text{LAP}})</td>
</tr>
<tr>
<td>Long-term morbidity</td>
<td></td>
</tr>
<tr>
<td>Myocardial infarction</td>
<td>(\text{LTQ}_{\text{MI}})</td>
</tr>
</tbody>
</table>

**TABLE IV** Utility Calculations for Clinical Example

<table>
<thead>
<tr>
<th>Outcome</th>
<th>DEALE Expression*</th>
<th>Life Expectancy (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coronary bypass/laparotomy/MI</td>
<td>(\frac{\text{LTQ}<em>{\text{MI}}}{\mu</em>{\text{ASR}} + \mu_{\text{CA}} + \mu_{\text{CABG}}} - \text{STM}<em>{\text{CABG}} + \text{STM}</em>{\text{LAP}})</td>
<td>4.03</td>
</tr>
<tr>
<td>Coronary bypass/laparotomy/no MI</td>
<td>(\frac{1}{\mu_{\text{ASR}} + \mu_{\text{CA}} + \mu_{\text{CABG}}} - \text{STM}<em>{\text{CABG}} + \text{STM}</em>{\text{LAP}})</td>
<td>4.25</td>
</tr>
<tr>
<td>Laparotomy/MI</td>
<td>(\frac{\text{LTQ}<em>{\text{MI}}}{\mu</em>{\text{ASR}} + \mu_{\text{CA}} + \mu_{\text{MEX}}} - \text{STM}_{\text{LAP}})</td>
<td>3.95</td>
</tr>
<tr>
<td>Laparotomy/no MI</td>
<td>(\frac{1}{\mu_{\text{ASR}} + \mu_{\text{CA}} + \mu_{\text{MEX}}} - \text{STM}_{\text{LAP}})</td>
<td>4.16</td>
</tr>
</tbody>
</table>

* For explanation of symbols, see Table III.
enience in expected utility of 2.3 units?" Using the DEALE, it is possible to report expected utility in a familiar format: life expectancy in years, adjusted by the patient and physician for possible morbid complications. The difference in quality-adjusted life expectancy between the two approaches is 0.10 years, or just over five weeks. This absolute difference can be comprehended by both the physicians and the patient, who now face the problem of determining whether the difference is sufficiently great to warrant coronary bypass surgery before proceeding to remove the cancer [17].

The DEALE can also be profitably employed outside of decision analysis. Clinicians have always been faced with difficult decisions in which they must correlate survival and quality of life data from diverse sources. Our approach enables the physician to evaluate such therapeutic options on a unified scale. Using the DEALE, the physician can list the possible outcomes, use diverse data from the literature to derive survival and morbidity values for each outcome, and transform the set of values into quality-adjusted life expectancies. Because morbidity and mortality are the two major components of outcome assessment, a decision that is obvious on the basis of these considerations often requires no further analysis. If the quality-adjusted life expectancies of different management plans are approximately equal (as in the case presented herein), other outcome attributes such as cost, psychological disability, or lost employment would have to be addressed [17].

There are some limitations of the DEALE approach. First, the value of life cannot be represented accurately for some persons with a simple linear model. Many people consistently choose options that avoid the possibility of immediate catastrophe, even though the average return on these options is diminished [10, 11, 18, 19]. The observation that people are willing to settle for "less" to avoid a loss (i.e., they are risk averse) parallels the observation that people often give more "value" to those years of life soon to occur than those in the distant future (a phenomenon known as discounting). The issues of "risk aversion" and "discounting" are not currently addressed directly within the DEALE framework, but slight modifications of the DEALE method allow consideration of these factors. Of course, other conventional methods do not address these issues either.

Second, the assessment of quality adjustments in life expectancy is still dependent on imperfect methods such as lotteries. We have found no substitute for a careful incorporation of patient attitudes into a clinical decision analysis. The DEALE method does not, of course, remove the limitations of utility theory. Third, the DEALE approach is constrained, by design, to considerations of mortality and morbidity. The science of clinical utility theory is not developed to the point at which "soft" psychological factors can be incorporated directly. Also, cost data have been difficult to incorporate directly into decision-making. Thus, hybrid measures such as "cost-effectiveness" are used when financial considerations or resource limitations become important [20]. In such applications, quality-adjusted life expectancies can be used as a measure of "effectiveness."

Outcome assessment has always been a difficult, often frustrating aspect of medical decision-making, but it is a crucial one if we are to make decisions based on sound clinical judgment. Although further work is needed to make utility analysis practical, we believe that the DEALE approach is a solid first step in pragmatic applications of utility theory. It can serve physicians and patients faced with difficult diagnostic or therapeutic decisions involving choices that limit survival or the quality of life.
REFERENCES