Decision Analysis

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INTRODUCTION

Decision analysis is a formal method to estimate the result of a clinical decision by assigning numeric values to the potential outcomes of that decision and to the probabilities of those outcomes. Analyses of many common clinical problems have been published (1-4). Decision analysis is most useful when uncertainty exists about the best course of action. One does not need a decision analysis to determine whether to obtain blood cultures in a patient with rigors, fever, and a new heart murmur. However, decision analysis would be an appropriate way to determine which antibiotics to use to treat that patient. Indeed, it would be an ideal situation for decision analysis; the clinical scenario is relatively common, and clinical trials have not definitively answered the question.

The process of decision analysis assumes that it is possible to rate the outcomes of a decision on a quantitative scale from best to worst. Thus, decision analysis is sometimes called a *normative process;* given the assumptions in the model, a "best" answer must exist. An analysis can be only as good as the abilities of the decision analyst and the quality of the data used. When little is known about a clinical problem, or when the decision analysis has been prepared by someone who is not familiar with what is known, even the most sophisticated analysis is unlikely to provide much that will be useful in caring for patients.

Although decision analysis is not the only way to approach a clinical problem, it has advantages compared with other methods of decision making under uncertain circumstances, such as dogmatism ("This is the best way to do it."), policy ("This is the way we do it around here."), nihilism ("It doesn't really matter what we do."), deferral to experts or patients ("What do you want us to do?"), and catastrophe avoidance ("Whatever else we do, let's be sure to not do that."). Especially when the correct decision is too close to call, small changes in one or two assumptions can change the results. The process of creating a decision analysis can often identify key pieces of clinical information that are unknown but essential to determining the best course of action. Decision analysis—because it assigns patient-specific values to the outcomes of clinical decisions—highlights the importance of patient preferences in physician decision making.

BASIC STRUCTURE OF A DECISION TREE

Decision analysis begins with a *clinical decision,* such as whether a patient with chest pain should be admitted to the hospital. The decision, of course, needs analysis only if the course of action is uncertain. Under many circumstances, as when a patient is severely ill, no uncertainty exists: admission to the hospital, not a formal decision analysis, is needed. For certain patients, however, the best decision is not clear.

A decision analysis is usually portrayed as a *tree structure,* progressing from the decision on the left to the outcomes on the right (Figure 7.1).

In general, the *decision* should be framed in terms of the clinical options and the characteristics of the patient and setting. Making a decision about hospitalization for chest pain will be different for a 75-year-old patient with known coronary artery disease than for a 35-year-old patient who runs 3 miles a day without symptoms. Suppose the clinical problem of interest concerns a patient between the ages of 50 and 59 years with new, but resolved, substernal chest pain. This patient has normal electrocardiographic findings and does not live alone. The decision is whether to admit the patient to the hospital or to treat at home with close

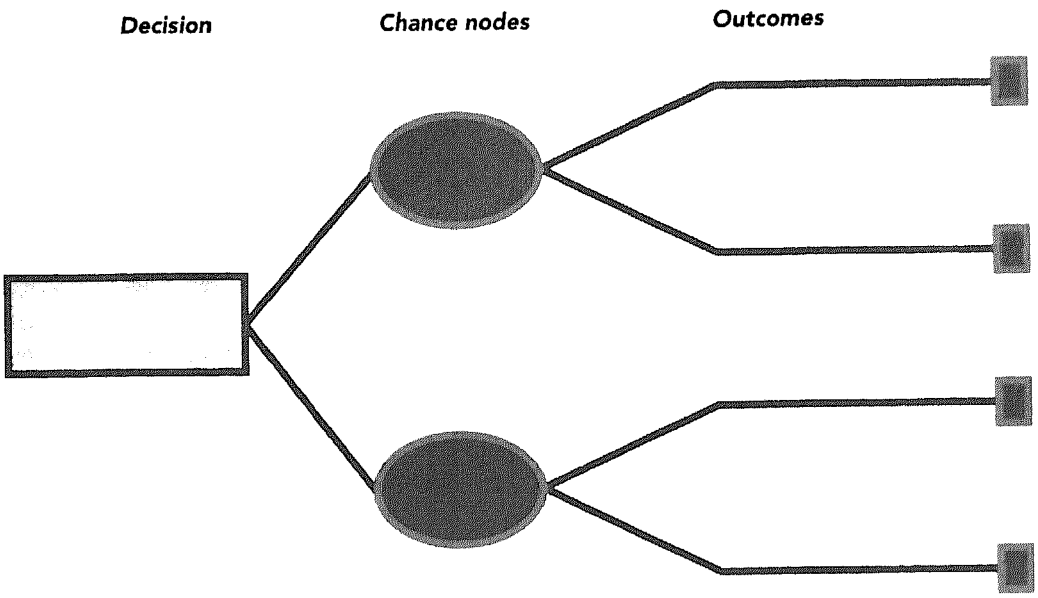

Figure 7.1 Basic structure of a decision tree.

follow-up. The outcome of interest is whether the patient survives the episode. By convention, the decision itself is placed in a rectangle, where each branch represents a different decision. Usually, a decision entails only two options, but additional choices are certainly possible, such as a brief admission to an observation unit. The same principles and techniques would hold.

After the decision node come the *chance nodes*, indicated with circles, which are used whenever clinical uncertainty exists. However, uncertainty from the clinical point of view may not be what matters in a decision analysis. For example, it may seem that the key uncertainty in deciding whether to admit a patient with chest pain is whether the pain is actually cardiac in origin. A more formal approach, though, may indicate that the actual uncertainties that matter are whether the patient has a problem that will get worse with outpatient treatment and how much more likely improvement is to occur with hospital admission.

A simple analysis of this decision (Figure 7.2) might begin with one set of chance nodes—the probability that a life-threatening problem will develop. A decision analysis ends with the *outcomes* of the different possibilities. In this case, four outcomes are possible: admitted and died, admitted and survived, treated at home and died, and treated at home and survived.

This simple tree does not reflect the clinical situation. A more realistic tree (Figure 7.3) needs at least one additional

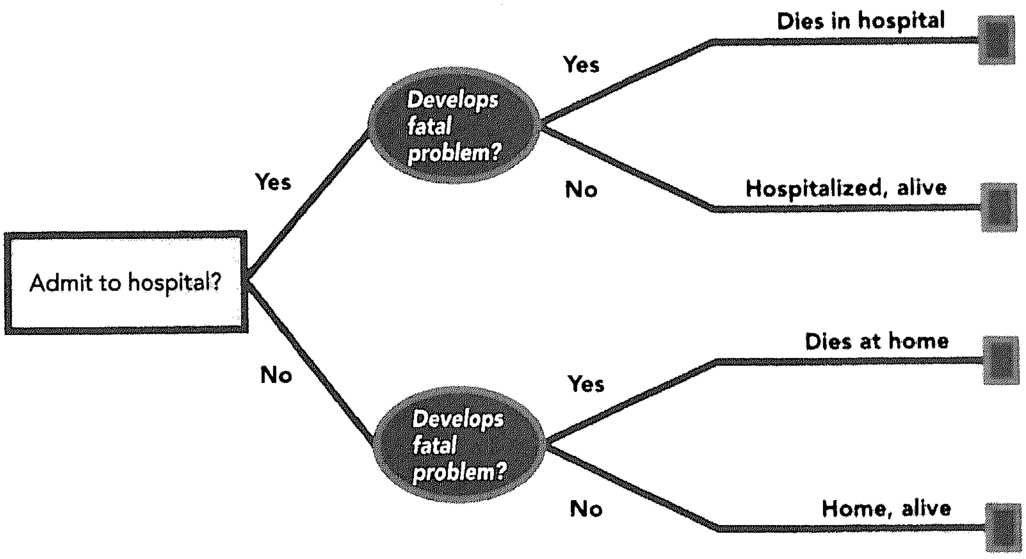

Figure 7.2 A simple decision tree for chest pain.

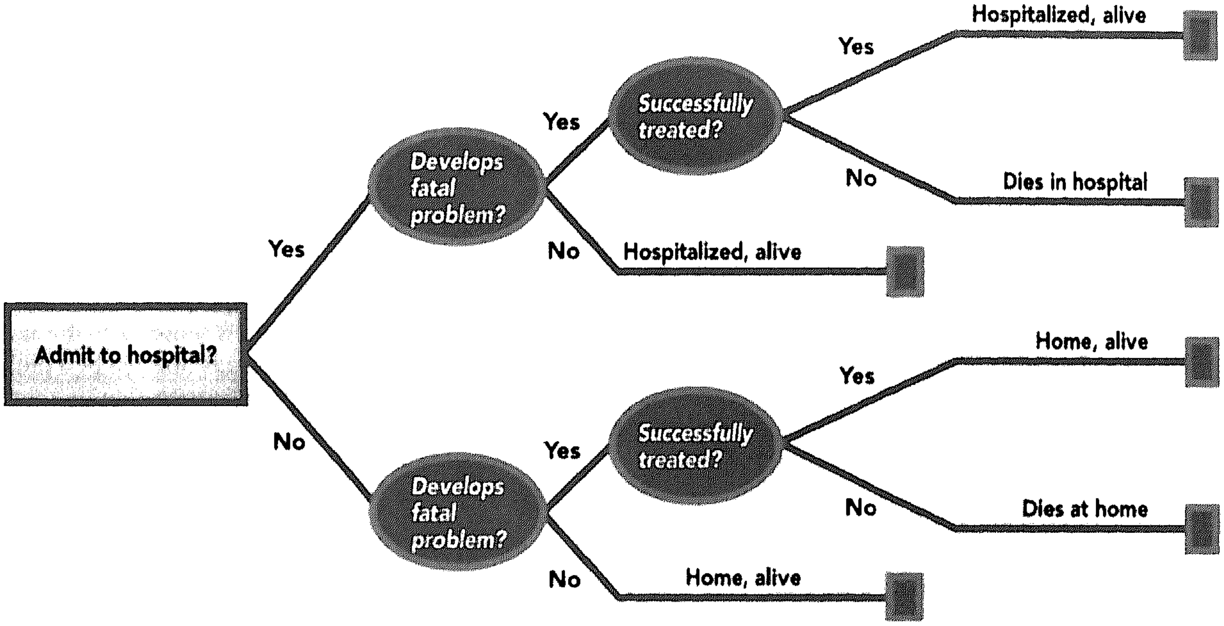

Figure 7.3 A more realistic tree.

layer of complexity—the likelihood that the potentially fatal problem can be prevented by therapy or detected and treated in time to prevent a fatal outcome. That likelihood is presumably greater if the patient is admitted to the hospital; if not, then hospitalization has no benefit, and no uncertainty exists about the right decision, which is to send the patient home.

In this more elaborate tree, the new set of chance nodes reflect the different probabilities. The chance nodes indicate the probability that a potentially fatal complication is destined to develop. This probability is independent of the decision; its likelihood is not influenced by the decision to admit the patient. This concept—that *the decision does not affect the likelihood that a patient already has a particular condition*—is essential to understanding decision analysis. If the patient is not destined to have a life-threatening complication, then the patient will survive whether admitted to the hospital or treated at home.

FILLING IN THE DECISION TREE

After the tree structure has been outlined, the next step in a decision analysis is to assign *probabilities* to the various branches leaving each chance node. The total probability at each chance node must sum to 100%. These probabilities can be obtained by a thorough review of the literature, from original data, or by asking experts. Although the most valid estimates of the effects of treatment are obtained from trials, these are not available for many decisions. Indeed, one of the strengths of formal decision analysis is that it is useful when a randomized trial is not practical or available.

In the example, let us arbitrarily assume that the likelihood that a life-threatening problem would have developed is 5%; thus, the likelihood that such a problem would not have developed is 95%. Next, one must estimate the likelihood of preventing or detecting and successfully treating this problem both at home and in the hospital. Let us assume that this likelihood is 80% if the patient has been hospitalized but only 50% if the patient is at home.

Numeric values must now be assigned to each outcome. These values are called *utilities*. For convenience, the best outcome (in this case, alive and at home) is usually assigned 100 points, and the worst outcome (in this case, dead) is assigned zero points. But how should the utility of the outcome of "alive and in the hospital" be valued? Some "disutility" must be assigned to hospitalization; otherwise, the best decision would be to hospitalize everyone, no matter how small the probability of the development of a life-threatening problem. This disutility results from the cost and inconvenience of hospitalization and from the possibility that the patient will suffer a hospital-related complication. Arbitrarily, let us assume that admission to the hospital for a condition that could have been managed on an outpatient basis has a disutility of two points; thus, the outcome of "alive and admitted" is worth 98 (100 − 2) points.

An important question to ask before assigning utilities is, "Whose utility?" Usually, the perspective for a clinical decision analysis is that of the patient. For example, a physician may view a death that occurs at home as being worse than a death that occurs in the hospital (in the sense that the death at home might have been avoidable had the patient been admitted). From the perspective of the patient, however, it is usually reasonable to assume that a fatal outcome has the same utility whether or not the patient was hospitalized.

ESTIMATING THE UTILITY OF EACH DECISION

After completing the anatomy of the tree and estimating all the probabilities and utilities (Figure 7.4), the decision analyst must determine the expected utility of each alternative decision. The expected utility of a decision is the average utility of all the possible outcomes of that decision, weighted by the likelihood of arriving at each outcome. The decision with the greatest expected utility is the best decision.

This process begins at the most distal nodes of the decision; the expected values at these nodes are determined by multiplying the utility of each outcome by the probability of the twig leading to that outcome. Then one sums the expected values of each twig. For example, a 20% chance of an outcome that is worth zero points and an 80% chance of an outcome that is worth is 100 points has an expected value of 80 points, or (20% × 0) + (80% × 100). This value becomes the expected utility of that chance node, which is then multiplied by the likelihood of arriving at that chance node. The process progresses centrally (from right to left) until the expected values of the original decisions, at the *base case* for the probabilities and utilities, are determined. In this example (see Figure 7.5), the decision to treat the patient at home results in an expected utility of 97.5, whereas admission to the hospital has an expected utility of 97.02 when using the base case assumptions about probabilities and utilities. Thus, the analysis indicates that treating the patient at home will have a marginally (less than a half point) greater expected utility.

SENSITIVITY ANALYSIS

The decision analyst next varies the assumptions in the model to determine how these changes affect the expected utilities of alternative decisions. This process is known as *sensitivity analysis* because its purpose is to determine whether the value of a decision is sensitive to the assumptions. Decisions that are not greatly affected by a probability or utility are said to be *robust* to that assumption. Sensitivity analyses alter the probabilities at each chance node as well as the utilities through a reasonable range. If only one assumption is varied, the process is known as a one-way sensitivity analysis. If several probabilities and utilities are varied simultaneously, these are called, for example, two-way or three-way analyses. Sensitivity analyses are especially important when the model contains several critical variables and there is disagreement about what the base case values should be.

One potentially confusing aspect of most sensitivity analyses is that the expected utilities of alternative decisions usually decline as the probability of an adverse outcome increases (Figure 7.6). For example, the value of admitting a patient with chest pain and the value of treating the patient at home both decline as the probability increases that a life-threatening complication will develop. That is because complications are usually a result of severe disease; even patients who are hospitalized may have adverse outcomes. However, a comparison of the expected values of the two choices shows that as the likelihood of

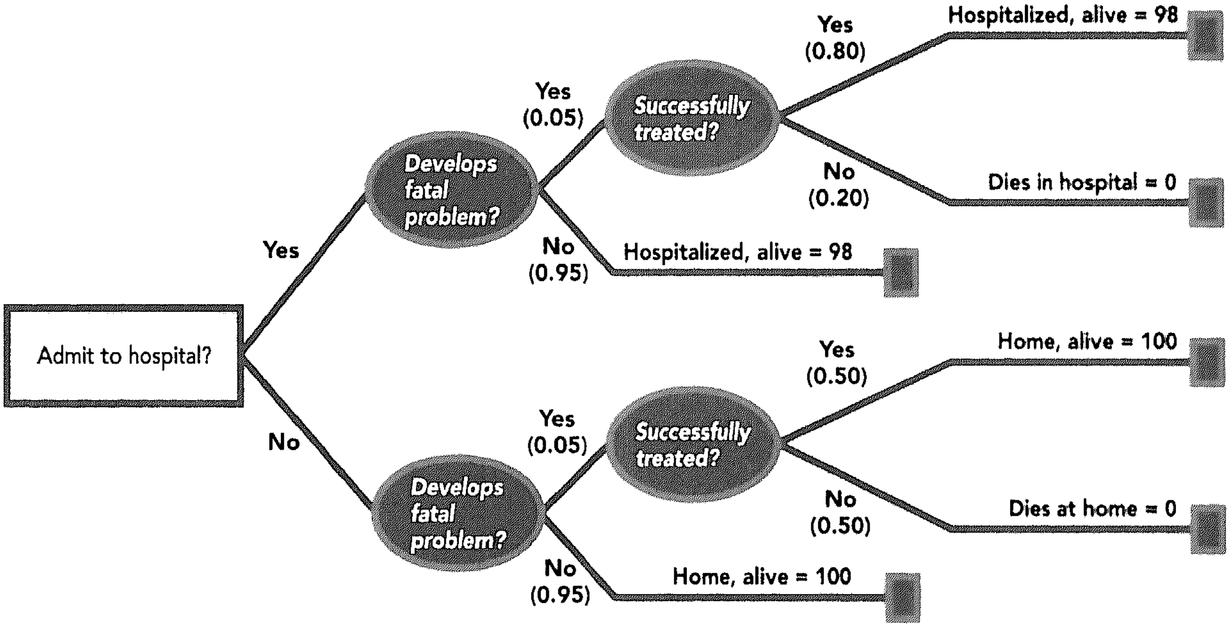

Figure 7.4 The tree with probabilities and utilities added.

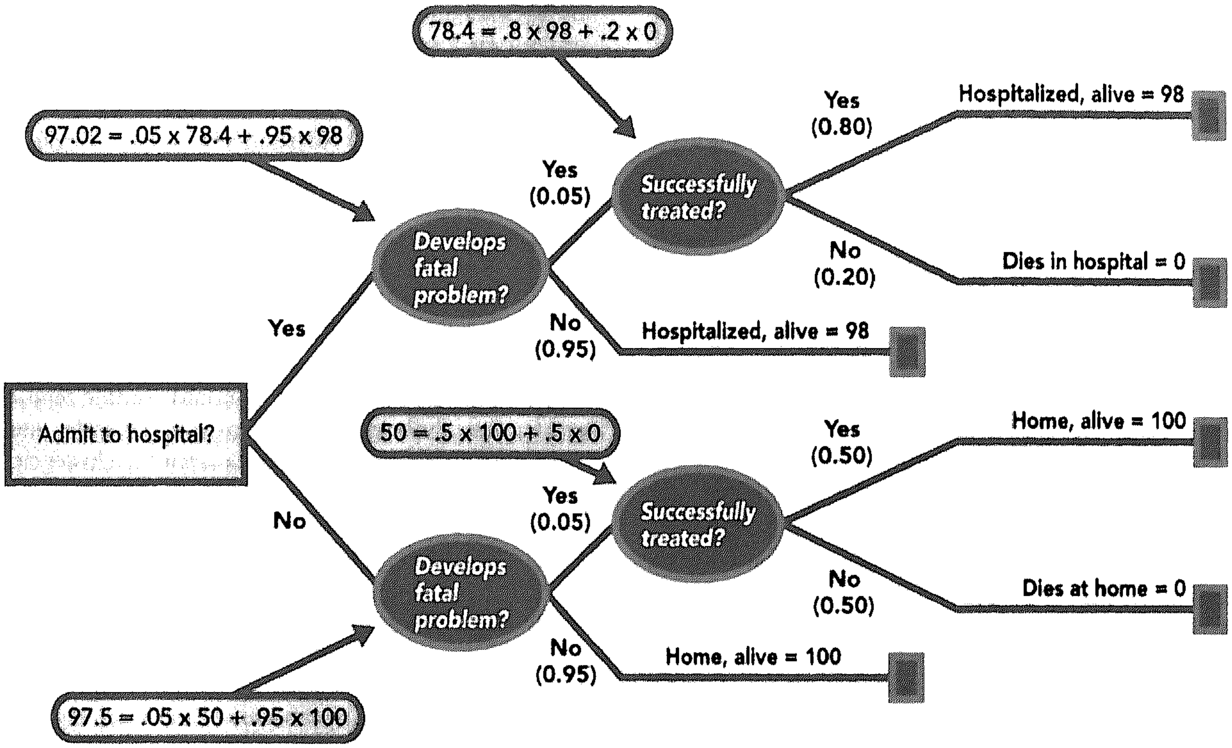

Figure 7.5 The tree with expected utilities *(elongated ovals)* added.

complications increases, the difference between the two therapies becomes more favorable to admission as the two lines diverge.

The point at which the expected values of alternative decisions are identical is the *toss-up* (5). In the example, this occurs when the probability of a complication is 6.6%. When the probability that the patient has a life-threatening condition is less than 6.6% (e.g., a 5% risk, as in the base case assumptions), treatment at home is preferred, albeit not by much. At probabilities greater than 6.6%, hospitalization is the better decision.

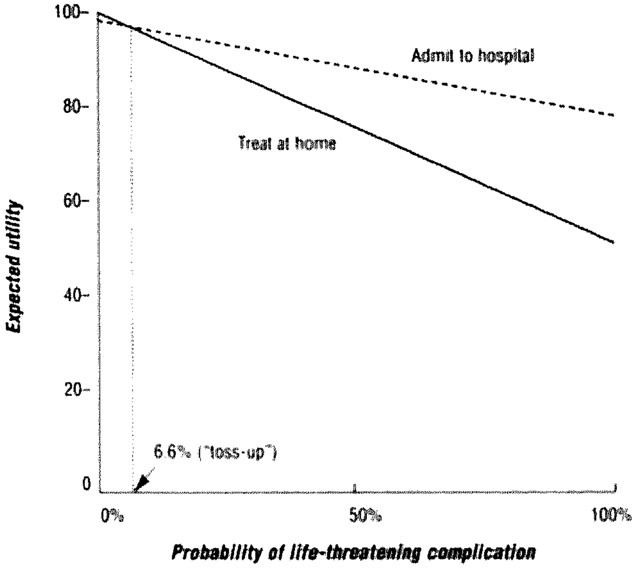

Figure 7.6 One-way sensitivity analysis of expected utilities of treating at home or admitting to the hospital, as a function of probability of life-threatening complication.

SETTING UTILITIES

One of the most difficult aspects of decision analysis is setting the utilities for the expected outcomes (6–9). Sometimes the utilities are obvious—for example, if there are only two of them (such as life and death). At other times, the utilities can be set in years of life expectancy under alternative decisions, such as survival with medical or surgical therapy in patients with left main coronary artery disease. However, for many situations, it is necessary to determine the utilities for one or more intermediate outcomes by using some sort of scale—the higher the utility, the greater the value to the patient.

Consider the following example. You are trying to help a patient determine whether to have femoral-popliteal artery bypass surgery for claudication. The patient is able to walk one block on level ground. The condition has been stable for the past year, during which time the patient has quit smoking. If the surgery is successful, the patient will be able to resume previous activities—walking several blocks a day—without pain. This is the best outcome, and it is assigned 100 points. The main complication of surgery is perioperative death. This is the worst outcome, and it is

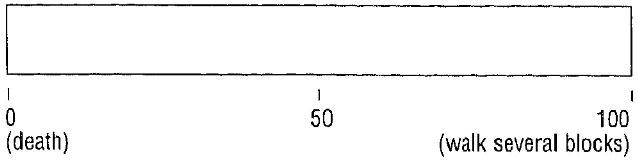

Figure 7.7 The linear utility scale.

assigned zero points. Assume that surgery is otherwise without problems. The utility that needs to be determined is that of the intermediate outcome—being "able to walk one block on the level."

One way to set this utility is to ask the patient, "On a scale of zero (death) to 100 (able to walk without pain for several blocks), how would you rate the current situation, with limited activity? Place a mark on the line that indicates your choice" (Figure 7.7). This is then the patient's utility.

Another way of assessing utilities is known as the *standard gamble* (Figure 7.8), in which the patient is offered two hypothetical scenarios. The first scenario is the intermediate outcome (e.g., living with claudication). The second involves balancing a chance of the best outcome (revascularization and pain-free ambulation) against the alternative of the worst outcome (death). When the chance of the best outcome is low enough that the patient has a difficult time deciding which scenario is more attractive, you have determined the utility of the intermediate outcome. This can be portrayed as a simple decision analysis to determine the probability of surviving a successful procedure that would make the decision a toss-up.

The patient needs to estimate the chance of surviving the procedure that would make the decision a difficult one (a toss-up). At that probability (P), the patient has determined the utility of the intermediate outcome because $P \times 100 + [1 - P] \times 0 =$ claudication utility. One can estimate this probability by beginning with a very high likelihood of surviving surgery and reducing it until the patient no longer chooses surgery. ("Suppose that surgery could restore your walking back to several blocks without discomfort. Would you choose to undergo surgery if the chance of surviving was 999,999 in a million? 999 in 1,000? 99 in 100? 49 in 50? 1 in 10? 1 in 2?") Alternatively, one can begin with a low surgical risk and increase it. ("Would you choose surgery with a risk for death of 1 in a million? 1 in 1,000? 1 in 100? 1 in 50? 1 in 10? 1 in 2?") If a patient is willing to take no more than a 1 in 20 chance of dying at surgery (at least a 95% chance of a good outcome), that implies that the patient has assigned the value of 0.95 to the utility of living with claudication.

Utilities derived from the standard gamble tend to be greater than those estimated using a linear scale; intermediate outcomes such as claudication tend to cluster close to those for good health. This happens because patients are risk averse and especially because they are death averse. Many are not willing to risk death to improve their current condition.

The standard gamble assumes that patients value a 95% chance of a perfect outcome the same as a 100% chance of an outcome that has a utility of 0.95. Some patients, however, may not like the uncertainty of not knowing and prefer a sure thing, even to the point of overvaluing it.

Often, utilities obtained from a linear scale or the standard gamble combine with life expectancy to yield *quality-adjusted life-years* (QALYs, pronounced "qwallies"). If claudication has a utility of 0.9, then the outcome of "alive for 10 years with claudication" would be equivalent to nine quality-adjusted life-years; so would nine years in perfect health (with a utility of 1.0) or 20 years with a health condition that had a utility of 0.45.

Another way to set utilities is by making time trade-offs to estimate the utility of a year of life in the intermediate state. In this method, the patient is asked to balance time in the current situation with time in a state of perfect health. For example, patients are asked whether they would be

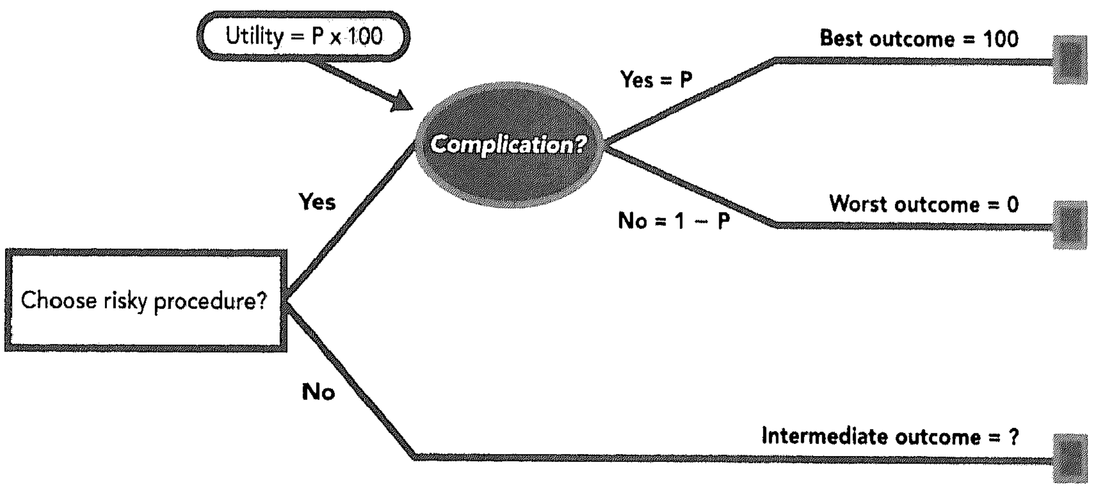

Figure 7.8 The standard gamble.

willing to trade 10 years of life with claudication for Y years of "revascularized" life (and death immediately thereafter). In this situation, patients are estimating the quality of life with claudication (e.g., on a scale of 0% to 100%):

$$\begin{aligned}&100\% \times Y\ \text{Years}\\&= \text{Quality of Life with Claudication} \times 10\ \text{Years}\end{aligned}$$

If a patient chooses eight years, this indicates that the current quality of life is 80%:

$$80\% \times 10\ \text{Years} = 100\% \times 8\ \text{Years}$$

In general, time trade-offs give values for utilities that are between those of a linear scale and those of a standard gamble. This occurs because patients, especially young patients, tend to devalue time given away in the future. They are more willing to give some away for the chance of feeling better.

Setting utilities from other perspectives can yield different results in a decision analysis. From the perspective of an insurance company or an overworked physician, admitting a patient to the hospital for five days of treatment for pneumonia has a major disutility, whereas from the patient's perspective, it may have only a minor disutility (or even none at all). Physicians may not value quality of life with a disability, such as the need for long-term dialysis, as highly as patients themselves do.

EVALUATING PUBLISHED DECISION ANALYSES

Before accepting the validity of a decision analysis, one must determine whether it is relevant to the clinical situation. First, are the alternative decisions actually available, or do they involve specialized or unavailable tests or procedures? Second, are the probabilities—both of outcomes and of the effects of treatment—valid in the particular clinical situation in which you find yourself? Were they based on referral populations? Were there other important differences, such as in age, gender, race, or stage of disease, in comparison with patients for whom you care? Were the relevant outcomes considered, and were they valued appropriately?

A well-performed decision analysis should also provide the exact structure of the decision tree that was used. If you cannot re-create the calculations involved in a complex model, then it is difficult to be certain that the authors did them correctly. A decision analysis that is not explicit about the tree structure can hide many branches and may have arrived at the wrong results.

Published analyses should provide the values for each probability for the base case and the ranges of probabilities for the sensitivity analyses, as well as references to the sources of probabilities. More importantly, an analysis should verify their relevance to the clinical situation. A decision analysis, for example, that concludes that anticoagulation is always the best course of action for patients with atrial fibrillation who have a risk for bleeding that varies between 1% and 10% a year would not be relevant for a patient who has had three gastrointestinal hemorrhages in the previous month.

Utilities should be appropriate. They are often set arbitrarily or by consulting with a few physicians, and thus they bear little resemblance to what patients might say. Bear in mind that most patients value life, even with disability or disease, highly, and that short-lived events (such as hospitalization) have only a minor effect on the quality of life for an entire year.

The advantages of decision analysis—that it requires an explicit structure of the decision, that probabilities and utilities must be estimated, and that a point of view must be adopted—also point to some of its key disadvantages. These requirements are time consuming and often not practical when a decision must be made in real time. However, formal decision analyses are available for many common clinical decisions, and many have been done well (1–4). The process of decision analysis, by highlighting the key uncertainties, may suggest areas in need of research. Many difficult decisions are toss-ups, and the process of decision analysis reminds clinicians of the importance of patient preference in these circumstances. Small changes in the utility of an outcome, such as a preference not to undergo an invasive diagnostic test, may greatly affect the preferred decision.

KEY POINTS

- Decision analysis is a formal method of evaluating clinical decisions made under circumstances of uncertainty.
- The process assumes that it is possible to rank outcomes from best to worst and to assign them numeric values, called utilities.
- The expected utility of a decision is determined by multiplying the utilities of each possible outcome of that decision by the likelihood of reaching that outcome.
- The best decision is the one that leads to the greatest expected utility.
- A decision is a toss-up when the expected utilities of alternative choices are similar.
- Sensitivity analyses determine the effects of changes in the assumptions of a decision analysis on the expected utilities.
- Different methods of setting utilities can result in different values.

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