The Principles of Clinical Decision Making: An Introduction to Decision Analysis

JEROME P. KASSIRER

Clinical Decision Making Group, Department of Medicine, Tufts University School of Medicine and the Medical Service, New England Medical Center Hospital, Boston, Massachusetts 02111
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INTRODUCTION

The ability to make the rational decisions that lead to optimum therapeutic outcomes is one of the cardinal characteristics of an outstanding clinician. Nonetheless, most of the energy expended in the education of medical students and house officers is directed into teaching a huge body of facts and methods for gathering and interpreting data; little or no attention is given to the principles that underlie clinical decision making. In fact, the principles of decision making are often obscured by the substitution of established protocols; that is, standard methods or rules of procedure for a given clinical situation. For example: Operate for suspected appendicitis, give digitalis for cardiac failure, or carry out renal arteriography for hypertension. The application of protocols has become so widespread that for many diseases students eagerly commit to memory a "treatment of choice." We are often chagrined when students or house officers proposed to give the usual therapeutic dose of digitalis to patients with myxedema or chronic pulmonary disease or when they recommend pulmonary arteriography in a patient with clear-cut evidence of pulmonary embolism. But should we be surprised? They are only following the rules that we have laid out for them, not going back to first principles.

In recent years a number of methods have been developed to complement the decision-making capabilities of the student and physician. One of these, decision analysis, found its earliest application in fields widely diverse from medicine such as military planning, economics, and marketing (1-3). Increasingly, this technique has filtered into the medical literature describing methods for dealing with clinical problems such as cancer (4), acute renal failure (5), pleural effusion (6), renovascular hypertension (7,8), appendicitis, and pulmonary embolism (9). Despite the potential usefulness of this explicit approach to the unstructured decision making that characterizes most clinical problems, decision analysis has not yet gained a foothold either in the curriculum or at the bedside. In part, lack of familiarity with the methods employed and with terms such as "decision trees," "chance nodes," "utilities," and "expected value" may account for the sluggish acceptance. This paper, an elementary introduction to the principles of decision analysis, will describe the method and some of the simple calculations involved, illustrate its use in the analysis of a complex clinical problem, and consider various aspects of its application in the practice and teaching of clinical medicine.
THE ELEMENTS OF A DECISION

Choosing between two or more possible courses of action requires that the choices are clearly identified and that a method is available to assess the overall value of the outcome of each choice. Two elements critically influence the decision-making process. First, our decisions usually must be made with some degree of uncertainty about the future. Second, the various possible outcomes of our decisions have different values to us.

Suppose we are invited for an ocean sail, but to reach the coast requires a 2-hr drive through heavy traffic; suppose also that on the morning of the outing we observe many ominous nimbus clouds in the sky. In this case, our decision will be influenced by the likelihood, or probability, of rain. We shall assume that, if we could be assured that it will not rain, we would venture forth, whereas, if we were certain that it will rain, we would not. In this example there is some uncertainty about the prospect of rain, and we must make an assessment about its probability. To make a logical decision we must also be able to make a subjective assessment of the value, or utility, or each possible outcome. If we decide to drive to the coast and weather conditions are favorable, the outcome will consist of good sailing (very high utility), but if heavy rains occur the outcome will consist of wasted driving effort (very low utility). On the other hand, if we decide not to take the drive and the weather is poor, the outcome will consist of avoiding the tedious drive and using the time at home constructively (moderately high utility). But if we stay at home and the weather remains excellent, the outcome is a loss of the pleasurable experience of sailing (low utility). Notice that each of these outcomes is quite different qualitatively, yet the decision maker must be able to state his preferences about the various outcomes and compare their values on a common scale.

The discipline of decision analysis encompasses all of these factors; it involves laying out the options and possible outcomes in explicit detail using a "decision tree," assessing the probabilities and values of each outcome, and selecting the "best" choice.

THE COMPLEXITIES OF A CLINICAL PROBLEM

Many of the elements of clinical decision making can be illustrated by considering the process a skilled physician might utilize in thinking about how to deal with a specific patient. Suppose a patient was encountered who had had a splenectomy a month earlier and now showed clinical findings suggestive, but not diagnostic, of a subphrenic abscess. The physician might consider many factors before deciding whether or not to operate. How likely is it that an abscess is present? Could the clinical findings be explained by a medically treatable disorder, for example, pancreatitis? If the patient is subjected to surgery, will a surgical or anesthetic complication occur, and how serious will such an event be? If surgery is carried out, will the surgeon be able to deal successfully with the abscess? How serious will it be if the lesion is not adequately excised or drained? What are the consequences of failing to operate if the patient has a surgically correctable lesion? Would a surgical lesion resolve under medical therapy? If so, how often would this occur and how often would complications occur? How serious would these complications be?

Though these questions and perhaps others should be considered in dealing with a clinical problem such as the one described, the integration of all this diverse information into a reasoned decision is not a simple matter. The integrative process is usually carried out in a tacit fashion, largely because most physicians do not have command of an explicit method for therapeutic decision making. Such an explicit decision-making method will be described here.
HELP THE QUARTERBACK

Before going on in greater depth into the principles of medical decision making, a simple example of the use of decision analysis will be shown for the reader unfamiliar with this technique: Though the example to be shown is not directly analogous to the problems encountered in clinical medicine, it does illustrate how probabilities and values can be expressed explicitly and how these elements can be incorporated into the decision-making process. Assume the following conditions:

The quarterback's team has possession of the ball on the 18-yard line of his opponent and with 1 minute left in the game his team trails by four points. It is the fourth down, with 5 yards to go for a first down.

Analysis. The choices are to pass, kick a field goal, or attempt a running play. Before the quarterback can decide which choice to make, however, he must know what the outcomes of each choice might be. A decision tree representing the choices and possible outcomes is shown in Fig. 1. At the square node, the choice is in the hands of the decision maker (the quarterback); at the circular nodes the outcome is dictated by chance. Next, the quarterback must assess the likelihood of each outcome. The probabilities he selects for each outcome are shown in Fig. 1. These probabilities are based not only on objective historical data (for example, the average yardage gained by his running backs, the success of his pass receivers, and the accuracy of his field goal kicker), but they are also tailored for the actual conditions of the game at that moment. Injury to his offensive line, experience with the defense earlier in the game, the condition of the field, psychological pressures, and many other factors will influence the likelihood of each of the possible outcomes and will make it necessary to make a subjective adjustment of some or all of the probabilities.

Even when the quarterback is assured that the probabilities represent his best

![Decision Tree](image)

FIG. 1. Decision tree for the football example described in the text. At the square node, the choice is in the hands of the decision maker (the quarterback), and at the circular nodes the outcome is dictated by chance. The probabilities of each outcome, as estimated by the quarterback, are shown on each branch.
judgment, he is not yet in a position to make a decision. Even though the probability of a field goal is 0.9, for example, its value is limited because it generates only 3 points and fails to win the game; on the other hand, the probability that a pass will lead to a touchdown is low, but the value of this outcome is high. It should be apparent from these remarks that the relative worth of each of the alternate courses of action is a function of both the probability of the outcome and the value, or utility, of the outcome. Thus, in order to obtain some index of the worth of each outcome it is necessary to develop an assessment of the utility of the outcome. In this case let us set up an arbitrary scale of relative units. On this scale, let us assume that a touchdown has the value of 1000 units, a field goal 20 units, and an intercepted pass –100 units. The utilities of the remaining outcomes and the relative value scale of all the possible outcomes are shown in Table 1.

![FIG. 2. Solution of the decision tree for the football example described in the text. The expected value of each node is shown in the accompanying oval. The expected value of the option to pass (133.2) exceeds that of running or attempting a field goal and the quarterback elects to pass.]

| CHOICES | OUTCOMES & PROBABILITIES | UTILITIES |
|---------|---------------------------|-----------|
| PASS    | COMPLETE (.40) TOUCHDOWN (1000) | (1000) |
|         | INCOMPLETE (.48) 1st DOWN (500) | (500) |
|         | INTERCEPTION (.06) SHORT OF 1st DOWN (.40) | (0) |
|         | FUMBLE FROM CENTER (.03) RECOVERY (.25) | (0) |
|         | THROWN FOR LOSS (.03) TURN-OVER (.5) | (.50) |
| ATTEMPT FIELD GOAL | GOOD (.90) | (.20) |
|         | NOT GOOD (.10) | (0) |
|         | TOUCHDOWN (.02) | (10000) |
|         | 1st DOWN (.15) | (5000) |
|         | SHORT OF 1st DOWN (.78) | (0) |
|         | FUMBLE (.25) RECOVERY (.5) | (0) |
|         | LOSS (.03) TURN-OVER (.5) | (.50) |
|         | RUN (.94) | (0) |

TABLE 1

| Outcomes                  | Utilities (units) |
|---------------------------|-------------------|
| Touchdown                 | 1000              |
| First down                | 500               |
| Field goal                | 20                |
| Short of first down       | 0                 |
| Incomplete pass           | 0                 |
| Fumble with recovery      | 0                 |
| Loss                      | 0                 |
| Fumble with turnover      | -50               |
| Intercepted pass          | -100              |
Having assigned both probabilities and utilities to each of the outcomes, the quarterback is now in a position to calculate the value of each outcome (Fig. 2). Starting at the terminal branches, the value of an outcome (for example, the top branch, "touchdown") is calculated by multiplying the probability of the outcome (0.1) and the utility (1000 units). When the values of the three terminal branches of the upper node (following "complete") are calculated, their sum (350 units) represents the expected value of that branch. Similar calculations are made from the end branches to the branches closest to the decision node. Then, after the expected value of all three choices have been calculated, the "best" choice is the one with the highest expected value. In the example shown in Figs. 1 and 2 the expected value of passing of 133.2 units exceeds that of the other options and signifies that the best choice is to pass.

Assuming the quarterback has made his analysis of this play in the detail described here, he is in an excellent position after the game to explain, and if necessary to defend, his decision. Any disagreements about the decision can be isolated and identified with reasonable precision because the decision-making process was explicit not only in the facts involved but also in the process by which the choice was made. Disagreements might involve the structure of the problem (i.e., the choices available) or the assigned values for the probabilities and utilities of each outcome. The value of this explicit approach in teaching the principles of decision making to the fledgling quarterback should be evident.

CLINICAL DECISION MAKING

The principal decisions made by physicians involve either the performance of diagnostic tests or the administration of a therapeutic procedure or agent. Such decisions involving both tests and treatments have features closely analogous to those in the football example described above: The physician must make a choice between treating and not treating; between one treatment and another or many others; between a test and a treatment; or between many tests and many different treatments. Uncertainty is also an important aspect of clinical medicine. The physician frequently must make therapeutic decisions in the absence of a proven diagnosis. Whether or not to operate for suspected ischemic colitis and whether or not to give a prolonged course of intravenous antibiotics for suspected endocarditis are two examples. Finally, both tests and treatments have a limited number of outcomes. These outcomes represent either a benefit or a cost (risk) to the patient and both a probability and utility can be assigned to each outcome.

The Costs and Benefits of Tests and Treatments

Assessment of the value of tests and treatments is a central aspect of the explicit decision-making process. Tests have more or less value depending on how much they advance the state of diagnostic knowledge for the patient in question. Tests with a relatively high frequency of false-positive and false-negative results (such as lung scans for pulmonary emboli) have less information content than tests with a low frequency of false-positives and -negatives (such as pulmonary and renal arteriography). Methods for combining data concerning the suspected diagnosis, the results of tests, and the errors inherent in test analysis will not be considered here but can be found elsewhere (5,7,10-15). The cost of the test must also be included in assessing its value. Cost may be assessed in terms of monetary expense, discomfort induced, or risk of death, or it may be represented in some uniform utility unit which combines all of these potential costs. Selection of tests based on a balancing of the benefits and
costs of the various tests available accounts for many of the familiar sequences in a diagnostic evaluation. In evaluation of a pulmonary lesion, for example, a typical sequence may be tomography and sputum cytology (very low cost, limited diagnostic value), followed by bronchoscopy (low cost, moderate diagnostic value), and finally lung biopsy (high cost, high value).

Treatments may also have value for the patient, but they, too, exact certain costs. Treatment may improve or cure the patient and it may induce a variety of complications. The benefit of the treatment can be measured in terms of alleviation of suffering or reduction in mortality or, as described above for tests, the benefit can be represented in a general utility unit that includes both morbidity and mortality evaluations. Similarly, the complications induced by treatment such as serious drug reactions, metabolic disturbances, postoperative wound infections, and death are the costs of therapy. These costs are paid not only by treated patients who have the disease for which therapy is prescribed but also by those patients who are thought to have the disease but in reality are either normal or are suffering from some other disorder not benefited by the treatment employed.

In order to determine the expected value of the outcome of administering a treatment it is necessary to assess several factors: (i) the probability of the various complications of therapy, (ii) the gravity (utility) of each of the complications, (iii) the probability of the various therapeutic outcomes, and (iv) the utility of each of the responses to therapy. To use a concrete example to illustrate alternative courses of action and possible outcomes: If a physician is deciding how to treat a patient in whom the diagnosis of mycoplasma pneumonia is highly likely, the problem might be expressed in the following fashion. Therapeutic choices include erythromycin, tetracycline, and no therapy. With erythromycin the patient may be cured, may improve, or may not change. In addition, erythromycin may induce nausea and vomiting, a drug rash, or a fatal blood dyscrasia. There is some probability and a certain utility of each of these outcomes. Similar considerations hold for tetracycline and, with the exception of drug-related results and complications, for no therapy.

Assessment of Probabilities

Clearly, the technique described here requires much greater precision in the assignment of probabilities than that which usually characterizes the daily practice of medicine. We often speak of outcomes that are infrequent, unusual, uncommon, or rare but, for each of these somewhat qualitative likelihood assessments, one individual may set the probability at 1 in 10, another at 1 in 100, and another at 1 in 1000! The same reasoning holds for the equally vague adjectives typical, common, frequent, and usual.

Empirical clinical studies are the basis of our determinations of the values and the risks of both tests and treatments and from these studies it is possible to derive reasonably accurate assessments of the probabilities of outcomes. An intravenous pyelogram, for example, is complicated by a risk of death of 1 in 40,000 and a risk of serious morbidity (anaphylaxis, arrhythmias, vascular collapse) of 1 in 14,000 (16). Chloramphenicol cures 95 in 100 patients with typhoid fever (17), but the risk of death from aplastic anemia is 1 in 30,000 (18).

Common sense dictates that such statistical data culled from the medical literature cannot and should not be applied to all patients. The risk of liver biopsy, for example, is considerably increased in the face of a disturbance in the coagulation mechanism. Similarly, the risk is increased if the biopsy is carried out by a novice or if adequate nursing supervision is not available in the several hours following the
procedure. Many factors such as the age of the patient, the hematologic status, the presence of coronary artery disease, and the history of drug sensitivity reactions call for an adjustment or tailoring of the probabilities involved for the specific cohort. In many instances data adjusted to various cohorts in various clinical situations have been collected in clinical studies, and it is possible to use accurate cohort-adjusted probabilities from these studies in explicit analysis of clinical decisions.

Objective measures of probability are not always available, however, sometimes because a certain type of clinical problem has not been studied adequately or because a test or treatment has not yet been widely utilized. In situations such as these, it is still possible to carry out decision analysis, deriving the probability values from subjective estimates. If, for example, the risk of nephrolithotomy in a pregnant woman with recurrent acute pyelonephritis cannot be found by search of either the gynecologic or the nephrologic literature, probabilities derived from a consensus of experienced gynecologists and nephrologists could be used when deciding whether or not to operate. Experience with decision analysis in a hospital setting confirms the clinical usefulness of such subjective assessments.

Assessment of Utilities

The assessment of utilities is more complex than the assignment of probabilities, chiefly because utilities are indices of value, and judgments concerning value must necessarily be subjective in character. A large variety of outcomes results from the various tests and treatments available to clinicians. On the positive side these outcomes include cure of a disease, alleviation of suffering, elimination or reduction of monetary expenditure, establishment of a diagnosis, and many others. On the negative side are outcomes such as physical and emotional disability, prolongation of hospitalization, pain, and death. In any given clinical situation several of these outcomes can be anticipated as a consequence of one or more of the decisions to test or treat. For this reason it is important to be able to compare the utilities of a number of outcomes with widely differing characteristics; for example, it is necessary to compare the potential positive value of alleviation of pain with the potential negative value of complications of a drug or surgical procedure that might be utilized to relieve the pain.

When all of the outcomes can be given a utility measured in a single unit (such as monetary cost) we can use so-called unidimensional utilities; they are readily ordered and compared. But medical outcomes are usually multifaceted; since outcomes such as pain, drug complications, and death are measured in different units, comparison and ordering of these facets requires that a common and consistent numerical utility unit be developed to express all of them. Such utilities are called multidimensional. If restoration of normal health were given a utility value of 100 units and if death following a prolonged painful illness were given a utility value of 0 units, a dollar expenditure of $5000 might be assigned 20 or 30 units, an anaphylactic reaction to a drug might be assigned 10 units, and improvement of health to the point where the individual could return to work on a part-time basis might be assigned 60 or 65 units, etc. Methods for assessing multidimensional utilities such as these in a consistent fashion are available but are too complex to be considered here in any greater detail (1, 19–21).

Though the assessment of probabilities is exclusively the responsibility of the physician, the assessment of utilities must be done in cooperation with the patient and the family. Since different individuals assess the value of outcomes differently, it is critical when assigning utilities to “debrief” the patient in order to use his or her sub-
jective judgments of values rather than those of the physician. There is a wide range of attitudes among patients toward the costs of tests and treatments. One 45-year-old patient may prefer to take antihypertensive medications for an indefinite period to the risks and discomforts involved in a diagnostic evaluation and surgical correction of hypertension that may be of renovascular origin. Another patient belonging to the same cohort with respect to age, cardiovascular status, and other features may prefer the risks of the diagnostic and operative maneuvers to the prolonged need for drug therapy.

In instances in which decision analysis is used for a class of patients rather than to solve the problem of an individual patient, it will be necessary to include in the assessment of utilities some measure of the value to society. Decisions regarding the allocation of scarce health resources often must take such considerations into account. Whether to allocate funds to programs for the patient with chronic renal failure or to programs for research into the causes of coronary artery disease are examples of decisions in this class that require utility assessments adjusted for the needs of society rather than for that of the individual.

APPLICATION OF DECISION ANALYSIS TO A CLINICAL PROBLEM

In an earlier section, the complexities involved in deciding whether or not to operate on a patient suspected of having a subphrenic abscess were outlined briefly. In this section decision analysis is used to solve a problem of such a patient actually encountered at the Yale-New Haven Hospital in late 1974. The example selected for this analysis involving a decision whether or not to treat does not, like many medical decisions, include an additional decision on whether or not to administer a test. This therapeutic problem is convenient for our purpose since the principles can be illustrated without undue complexity.

Two decisions whether or not to operate will be considered; the first on December 8, when the diagnosis of subphrenic abscess was not very likely and the patient was only moderately ill; and the second on December 24, when the diagnosis was more certain but the patient had become seriously ill.

Decision 1

(a) Initial clinical course (up to December 8). A 24-year-old woman had both kidneys removed in February, 1972, for bilateral hypernephromas. After a stormy clinical course on dialysis complicated by pericarditis and severe neuropathy, she received a kidney transplant from a cadaver donor in October, 1974. Early in November, 1974, a splenectomy was carried out to correct leukopenia and thrombocytopenia that had impeded the continuance of immunosuppressive therapy. Late in November she was successfully treated with cephalosporin for Klebsiella sepsis and left lower lobe pneumonia. On December 3, 1974, she was readmitted to the hospital with fever (104.2°F), nausea, vomiting, and diarrhea and was found to have rales in the left base but no abdominal findings. Over the next several days, the symptoms intensified and on December 8 she had severe left upper quadrant abdominal pain radiating to the left shoulder, generalized abdominal tenderness, diminished bowel sounds, splinting of the left chest, and poor movement of the left diaphragm. The white count was 8900. The diagnosis of subdiaphragmatic abscess was considered at this time, and the possibility of surgery was first raised. The decision tree in Fig. 3 is a representation of this decision.

This paper is based on a presentation at Medical Grand Rounds at the Yale-New Haven Hospital in February, 1975.
(b) Summary of the decision-making process. The choices (Fig. 3, square node) available to those responsible for the patient were either to operate or not to operate, and the consequences of both choices can be described explicitly. On December 8 there was considerable uncertainty about the diagnosis of subphrenic abscess. If surgery were carried out (upper branch), a surgically correctable abscess may or may not be present. Following the branches in the figure across from left to right, a series of possible outcomes is represented: Whether the lesion is present or not, the patient may suffer a complication of surgery and the complication may or may not be serious. If a surgically correctable lesion is found, it may or may not be possible to fully evacuate the abscess. If the abscess can be evacuated, the outcome should be excellent; however, if it cannot be fully removed, the lesion may resolve with medical therapy or may lead to sepsis and death.

The outcomes of medical therapy are represented in Fig. 3 in a similar fashion. If surgery is not carried out, the patient will presumably recover if a nonsurgical lesion (for example, acute pancreatitis) is the cause of the illness (lowest branch). If surgery is not carried out and the patient actually has a surgically correctable lesion, the outcome would be nearly the same as the lesion described above that was not entirely removed surgically: There would be some chance of spontaneous resolution and some chance of a serious outcome.

(c) Assessment of probabilities. We shall assume that on December 8 the probability of a surgically accessible lesion was 0.3 and that of a nonsurgically accessible lesion was 0.7. Stated in other terms, we have estimated that 30% of patients
with a clinical picture comparable to that shown by this patient on this date would have a subphrenic abscess and 70% would not (Fig. 3).

Some of the probabilities required for the analysis of this problem were found in clinical studies of patients with subphrenic abscess (23–27). The other probabilities utilized here were estimates of an experienced abdominal surgeon (28). The mortality rate in operated patients averages 25% (range 16–43%) and in nonoperated patients ranges between 43 and 85% (23–26); a value of 55% was used for this latter group. Serious complications (fistulas, abscess rupture, sepsis, cardiovascular complications) occur in another 25% of the operated patients and in approximately 20% of the nonoperated patients (28). In approximately 10% of the patients the abscess is not adequately drained in the initial operative approach (28). The mortality rate in this group of patients is 55% (23). The probabilities utilized in the decision tree in Fig. 3 for December 8 are derived from these data.

(d) Assessment of utilities. The utilities used in these analyses (Table 2) were derived by the author; the patient was not available when this analysis was carried out. In the nonmedical example illustrated earlier, both positive and negative utilities were used to assess the value of outcomes. In this clinical example only positive utilities will be used in order to demonstrate that either scale is applicable when solving complex decisions in this fashion. The best outcome, i.e., spontaneous resolution of either a surgically correctable lesion or a nonsurgical lesion was assigned 100 units. The worst outcome, i.e., death, was assigned 0 units. A toll of 5 units was exacted for the discomfort and expense of surgery whether or not a surgically accessible lesion was present. A toll of 30 units was paid for a serious surgical complication assuming that such a complication would entail discomfort, prolongation of hospitalization, loss of income, and psychological consequences. Finally, a toll of 40 units was paid for serious complications of a surgically correctable lesion in the patient not subjected to surgery.

(e) Calculations and results. As shown in Fig. 3, on December 8 the expected value for surgery is 62.5 units and that of no surgery is 81.1 units. Since the expected value of no surgery exceeds the expected value of surgery, the best decision on that date is to treat the patient medically.

Decision 2

(a) Later clinical course (December 8 to December 24). On December 8 it was decided to treat the patient with nasogastric suction, fluids, and antibiotics rather

| Outcomes                                                                 | Utilities (units) |
|--------------------------------------------------------------------------|-------------------|
| No surgery, spontaneous resolution of lesion                             | 100               |
| Surgery, no complication, lesion repaired                                | 95                |
| Surgery, no surgical complication, lesion not repaired surgically, serious complication of lesion | 65                |
| Surgery, serious surgical complication, lesion repaired                  | 65                |
| Surgery, serious surgical complication, lesion not repaired but resolved spontaneously | 65                |
| No surgery, surgically correctable lesion, serious complication of lesion | 60                |
| Surgery, serious surgical complication, lesion not repaired, serious complication of lesion | 25                |
| Death                                                                    | 0                 |
than explore the left flank. Over the next several days, the patient improved but within a week the same symptoms recurred. On December 15 an ultrasound study gave suggestive evidence of a collection of fluid near the tail of the pancreas and a gallium scan showed increased uptake in the area of the splenic flexure. Again the patient improved on a regimen consisting of nasogastric suction, fluid therapy, and antibiotics, but on December 24 all of the previous symptoms recurred, the white count was found to be 12,600 with a shift to the left and a space was identified between the stomach and the diaphragm on an abdominal plain film. The patient appeared acutely and chronically ill; her blood pressure was 70/50 mm Hg. Again a subdiaphragmatic abscess was suspected and the possibility of surgery was raised. The decision of December 24 is also considered in detail below.

(b) *Summary of the decision-making process.* As shown in the decision tree in Fig. 4, both the choices available (surgery vs no surgery) and the possible outcomes on December 24 are the same as those described earlier.

(c) *Assessment of probabilities.* By December 24, the new data available from the evolving clinical course, the change in white cell count, and the results of echography, scan, and plain film markedly increased the probability of a surgically accessible lesion. We shall assume that this a priori probability is 0.95, and thus the a priori probability of a nonsurgically correctable lesion is 0.05. Many of the probabilities utilized in the decision tree in Fig. 4 for December 24 were not found in a review of published cases because data on nonoperative resolution of the abscess and complications were not available for a cohort of patients whose illness was complicated by hypotension and sepsis. For this date, the probability of a serious complication of surgery was estimated to have increased from 0.25 to 0.50 and the probability of death

![Decision Tree](image)

**FIG. 4.** Decision tree for the same patient shown in Fig. 3 but for a later date (December 24). At this time the probability of a surgically correctable lesion is very high and the "best" decision is to operate (expected value of surgery exceeds that of no surgery), even though the risks of serious complications and death from surgery have increased.
from 0.25 to 0.40. Likewise, the probability of nonoperative resolution of the lesion was estimated to have fallen from 0.25 to 0.10, and the probability of death from an unoperated surgically correctable lesion was estimated to have increased from 0.55 to 0.70 by December 24.

(d) Assessment of utilities. The utilities employed in the analysis of the decision of December 24 are the same as those used earlier.

e) Calculations and results. On December 24, as shown in Fig. 4, the risk of surgery has increased remarkably because of the deterioration in the patient's clinical state. Nonetheless, the expected value of surgery at that time (38.9 units) exceeds that of no surgery (25.9 units) and the surgical approach is warranted despite the very high risk. One of the chief reasons why the surgical approach is favored stems from the striking increase in the probability of a surgical accessible lesion, from 30% on December 8 to 95% on December 24.

It is of considerable interest to compare the final expected values for the decision on December 8 and December 24 to the scale of utilities in Table 2. The derived expected values are a measure of the overall worth of each therapeutic choice; they are measured in the same units as the utilities assigned to the individual outcomes illustrated on the end branches, and they belong to the same relative value scale. Accordingly, the expected value of each choice can be compared to the utility of cure and of dying and to the other outcomes. On December 8 the expected value of the best choice, i.e., no surgery, was 81.1 units, a value high on the utility scale. On December 24, however, the expected value of the best choice, i.e., surgery, was only 38.9 units, a value greater only than that for death and for multiple serious complications. Thus, even the best outcome on this date has serious prognostic implications.

Some of the advantages of this approach should be evident by studying the two decision trees shown for this patient. Outcomes, probabilities, and utilities are displayed for ready inspection. Comparison is easily carried out between the earlier and later decisions. Students observing the decision-making process openly displayed can readily understand the principles used and the data that were employed. All in all, the technique represents a considerable advance over the obscure decision-making processes more often utilized.

DISCUSSION

In this paper the principles of decision analysis have been described, and the method has been illustrated for a patient suspected of having a subphrenic abscess. In carrying out this type of explicit analysis of a clinical problem, a decision tree is constructed to include the choices (options) available and the various outcomes of each choice. Assignment of a probability and utility (a measure of worth) of each outcome completes the decision tree and a simple arithmetic calculation yields an "expected value" for each option. The option with the highest expected value is then selected as the best balance between risks and benefits.

Practical Applications

In the example cited in detail above, the method was used in its entirety: All major outcomes were considered, probabilities and utilities were assigned to all outcomes, and a formal calculation of expected value was carried out. Experience with decision analysis in a clinical inpatient setting shows that the complete mathematical analysis carried out as in the example above is needed for only a small fraction of the complex clinical problems encountered on a day-to-day basis. Very often construction of the decision tree alone forces the physician to do one of the tasks that is often ignored:
anticipating the possible outcomes of a given action. Why carry out a renal arteriogram if the result will be of no value in treating the patient; why carry out a liver biopsy if there is virtually no expectation that therapy will be altered by the information obtained? Explicit definition of the possible outcomes tends to prevent this common trap.

In the clinical situations in which formal construction of a decision tree appears warranted, methods are available for simplifying the tree and its attendant calculations. This method involves eliminating (pruning) branches of the tree, making it less “bushy.” Branches can be pruned only if it is obvious from inspection that the probability and utility of the outcome are such that their combination will yield a value that will contribute little or not at all to the expected value of the outcome. A detailed description of a pruned version of a “bushy” decision tree is presented in detail elsewhere (7).

Sensitivity Analysis

Experienced clinicians appreciate that even the “objective” data from clinical studies often represent only an approximation of the probability of a given outcome. They are accustomed to discrepancies between two clinical studies: One may show a response rate of 60% and another rate of 80%; one may show a 1% rate of serious complications of a procedure and another a 5% rate. Such discrepancies as well as variations in subjectively assessed probabilities (and utilities) do not abrogate the usefulness of decision analysis in clinical medicine. Rather, they enhance the value of this technique. Because the decision is laid out explicitly, it is possible to test the impact of discrepant values on the final decision. This process of testing whether variations in probabilities or utilities influence a given decision is known as “sensitivity analysis.”

The process can be illustrated nicely by the clinical problem of subphrenic abscess considered earlier. On December 8 the expected value of surgery was 62.5 units and the expected value of no surgery was 81.1 units; thus no surgery was the “best” choice. These expected values were based in part on an operative mortality rate of 25%. In fact, studies of patients with subphrenic abscesses have reported operative mortality rates ranging between 16 and 43% (23–26). If we use each of the values bounding this range and recalculate the expected value of surgery (keeping the probability of a serious surgical complication constant), the two expected values for surgery are 71.0 and 45.8 units for mortality rates of 16 and 43%, respectively. Since both of these expected values are lower than the expected value of no surgery, the decision stands as before: The “best” decision on December 8 is not to operate. Thus, the decision was not sensitive (i.e., not changed) throughout the range studied for this particular variable, namely the operative mortality rate.

Similar analysis could be carried out for any of the probabilities or utilities used. If the decision proves to be sensitive to one or more of the values substituted, additional data gathering or more careful consideration of existing data may be necessary. Unfortunately, sensitivity analysis can be tedious if it becomes necessary to test a large number of probabilities or utilities. Computer analysis simplifies this task but is not generally available. A new technique of sensitivity analysis that can be applied to therapeutic decisions without the aid of a computer has been described elsewhere (9). This technique, derived from decision analysis, is applicable in a wide variety of medical and surgical settings and has been illustrated for two common clinical problems, pulmonary embolism and acute appendicitis. No matter which method is used,
however, sensitivity analysis makes it possible to assess the importance of "soft" clinical data on the decision-making process.

**Importance of the Outcome in Assessing the Decision**

Decision analysis emphasizes the seldom appreciated phenomenon that outcomes predicated on probabilities are dictated by chance alone. Restated in terms of problems that physicians face, rational decisions made on the basis of the best data and value judgments do not always lead to the best outcomes and, in fact, poor decisions sometimes yield excellent outcomes (21). These principles are readily illustrated. Suppose a patient without a history of allergy or drug sensitivity is given penicillin for pneumococcal pneumonia and has a fatal anaphylactic reaction to the drug. In the case of pneumococcal pneumonia, penicillin therapy has been shown to have a high expected value: The fatal outcome was an event with a very small statistical likelihood. Here the decision was excellent, the outcome grave. Suppose, on the other hand, a patient with cirrhosis of the liver and impending hepatic coma develops massive gastrointestinal hemorrhage. Let us also assume that survival in such a patient with surgery is 2% and with medical therapy 10%. An aggressive surgeon may decide to operate "in the small likelihood that the lesion can be repaired and the life of the patient saved." If he operates and the patient recovers, the outcome is excellent. Nonetheless, the decision was not.

Interpretation of outcomes is important when large numbers of cases are analyzed, but to judge the quality of the decision by the outcome in a single case must be done with great caution. It follows, therefore, that as long as a decision is made properly, an untoward outcome should not be construed as an error in judgment. It also follows, however, that good decision makers should achieve better results on the average than those who have a predetermined pattern of response for each class of clinical problems.

**Problems Yet to be Solved**

It is important to point out that the techniques of decision analysis have been used only to a limited extent in a medical environment, and it is too early to assess the potential applicability of this method. Certain areas require particular attention, further research, and considerable practical clinical experience. One of these areas is the assignment of probabilities to outcomes. This process can be enhanced by collecting large bodies of clinical data concerning the values and risks of tests and treatments specific to a variety of cohorts. In order to make an accurate estimate of the probability of the morbidity and mortality of biliary tract surgery in a given patient, clinical studies could be designed to collect data specific to the patient's age, sex, weight, and cardiovascular status and to a variety of external factors such as the expertise of the surgeon, the abilities of the anesthesiologist, and the availability of house staff for adequate postoperative coverage. We have yet to learn how much the estimates of probabilities by experienced clinicians deviate from such "hard data" and what impact this deviation has on the decision-making process.

A second area requiring further study is utility assessments. The arbitrary assignment of numerical values to outcomes such as pain, disability, and death is foreign to patients and physicians alike. Though physicians tend to become less uncomfortable with such utility assessments as they become experienced with decision analysis, the popular appeal of the technique will probably be impeded unless some kind of medically compatible multidimensional utility assessment can be developed.
A third area requiring considerable study is the estimation of a priori probabilities of medical diagnoses. Although students and physicians seem to be able to make such estimates readily, the factors influencing such judgments have not been characterized. In one nonmedical study of subjective probability assessments, a large number of factors were found that importantly influenced the judgments (29). A comparable study in medicine has not yet been carried out.

Finally, some method might be devised for comparing the judgments of one group of physicians using conventional methods and another comparable group using decision analysis. Such an experiment is difficult to design but is probably feasible.

Although these various problems appear formidable, many or perhaps all are subject to scientific study and none is obviously insoluble. Given the anticipated widespread application of decision analysis in the daily practice of medicine and in the education of future physicians, it is highly desirable for the informed physician to be familiar with the potential values and the limitations of this technique.

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