OVER the past 15 years, clinical decision analysis has become an important tool in approaching difficult medical problems.\textsuperscript{1, 2} It has aided clinicians in making decisions not only for individual patients but also for groups of patients with common clinical problems. Oftentimes, the analysis has provided a perspective different from the clinical judgment of the physicians involved in the care of certain patients.

The field of renovascular hypertension has also undergone tremendous growth and change over the past few years.\textsuperscript{3-4} Decision making regarding the optimal therapy for patients with renovascular disease has been hampered by the lack of controlled studies comparing the various options. With the recent advent of renovascular angioplasty, selection of the appropriate therapy has become even more confusing. The following complicated case of renovascular hypertension illustrates how decision analysis can be helpful in this setting.

**Case History**

A 59-year-old white woman with a long history of vascular disease had been hypertensive since at least 1968. Her blood pressure had never been well controlled. In 1976 a renal arteriogram revealed a 50\% narrowing of the proximal left renal artery and minimal narrowing of the right renal artery at its origin. Renal vein renin levels were low and equal on both sides, and the serum creatinine level was 1 mg/dl. She was thought to have severe essential hypertension and continued to receive medical therapy. In 1979 the creatinine level was 1.7 mg/dl.

She was first seen by one of us (R.K.) in November 1981. Her blood pressure at that time was 220/114 mm Hg despite treatment with captopril, metoprolol, and spironolactone. The serum creatinine level was 3.4 mg/dl. In January 1982 a renal arteriogram showed a small nonfunctioning right kidney. Renin levels were markedly elevated in the right renal vein and low in the left renal vein. A right-sided renal angioplasty was unsuccessful, and a right-sided nephrectomy was performed. Her blood pressure became more easily controlled, and serum creatinine stabilized between 3.5 mg/dl and 4.0 mg/dl. Over the next 3 years her clinical condition remained stable. In early 1985 her blood pressure began to rise to levels as high as 210/140 mm Hg. Serum creatinine was stable at 4 mg/dl. Because of the suspicion that left renal artery disease had progressed, consideration was given to a repeat arteriogram and either surgical bypass or renal artery angioplasty if feasible.
The patient had numerous other medical problems. She had diffuse vascular disease, including cerebrovascular disease for which she had undergone a successful right temporal artery-midbrain arterial bypass in 1979. She had stable, exertion-induced angina pectoris requiring approximately 4 to 6 nitroglycerin tablets per day. She also had bilateral lower extremity claudication. She smoked two packs of cigarettes per day but denied alcohol excess. She had no history of diabetes. Her resting electrocardiogram showed left ventricular hypertrophy and nonspecific repolarization changes. A dihydralazine thallium scan was normal.

A decision analysis consultation was requested to assess the best approach to the treatment of her renovascular disease.

Application of Decision Analysis

The Problem Stated

What is the best way to preserve renal function in this patient with presumed renal artery stenosis in a solitary kidney: medical therapy, percutaneous transluminal renal angioplasty (PTRA), or renal artery bypass (RAB)? Medical therapy does not involve an immediate risk of death or dialysis but provides the least protection of renal function. PTRA involves immediate risk but presumably provides greater protection of renal perfusion and function. RAB involves the greatest immediate risk but offers the greatest potential benefit. The trade-off between the risks of the procedures and the benefit of long-term preservation of renal function is the focus of this analysis.

This question involves a choice among three strategies. Although the initial decision is between medical therapy and renal artery catheterization, catheterization should not be performed unless an intervention, either PTRA or RAB, is to follow if the test is positive. However, if technical difficulties preclude PTRA, another "downstream" decision must be made: medical therapy could be continued or RAB could be performed. The physicians caring for this patient did not think that medical therapy after an unsuccessful PTRA was a reasonable option. Three therapeutic options were therefore considered: 1) provide medical therapy only, 2) perform RAB, or 3) attempt PTRA but perform RAB if the PTRA is unsuccessful (PTRA/RAB).

Assumptions

We made the following assumptions in developing our analytic model:

1. The patient has renovascular hypertension.
2. Renovascular disease is contributing to the patient's renal failure.
3. Blood pressure can be adequately controlled with medication, and there is no quality of life forfeited by taking medicine. Therefore, the only advantage to an intervention is the preservation of renal function.
4. If the patient's renal artery lesion is not bypassable, it is not amenable to angioplasty.
5. If the patient's renal artery lesion is bypassable but not amenable to angioplasty, RAB will be performed.
6. All patients in whom RAB is unsuccessful will require long-term dialysis.
7. If dialysis is needed, it will be required for the remainder of the patient's life. Temporary dialysis was not a consideration.
8. A single PTRA will be attempted. Our model does not examine repeat angioplasties.

Structure of the Model

We developed a two-part model. The first part contains a decision tree representing the options available to the physician and calculates the likelihood that various outcomes will occur if a particular strategy is chosen. This tree depicts the events associated with catheterization, PTRA, or RAB. In the second part, a Markov process is used to calculate life expectancy as the patient evolves through the various health states associated with progressive renal disease.

Figure 1 shows the decision tree. Square nodes represent decisions, and circular nodes represent chance events. At the far left of Figure 1 is the initial decision node depicting the choice between medical therapy, RAB, and PTRA/RAB. If medical therapy is chosen, the patient's prognosis is modeled by a Markov process (Figure 2). In the RAB and PTRA/RAB strategies a catheterization is initially performed. In Figure 1, the first circular node for each of those strategies depicts the chance of dying from dye-induced anaphylaxis (labeled die) and the chance of dye-induced renal failure leading to chronic dialysis (labeled dialysis). The prognosis of patients who need dialysis for any reason is modeled by a Markov process. If death or dialysis does not occur as a result of catheterization, the second chance node that is encountered depicts the possibility that the renal artery lesion is amenable to surgical bypass. If the lesion is not bypassable, prognosis is again modeled by a different Markov process. In the RAB strategy, if the lesion is bypassable the next chance node depicts the chance of death, dialysis, or successful RAB. Long-term prognosis is determined by using several Markov models.

In the PTRA/RAB strategy, if the lesion is bypassable the third chance node indicates the possibility that the lesion is also amenable to angioplasty. If it is not amenable to angioplasty, RAB will be performed. If the lesion is amenable to angioplasty, the next chance node depicts the possibilities of PTRA-associated death or dialysis. If death does not occur and dialysis is not required, the next circular node depicts the chance of renal artery occlusion. If occlusion does not occur, the next chance node depicts the possibility of a successful PTRA. The prognosis of these patients is again calculated using
FIGURE 1. Decision tree. The decision process flows from left to right. Square nodes depict decisions to be made, circular nodes depict chance events, and rectangular nodes depict terminal states. The diamond-shaped nodes link branches to the Markov process. The bracket connects the enclosed branches to the subtree that follows. MED = medical therapy; CATH = catheterization; RAB = renal artery bypass; PTRA = percutaneous transluminal renal angioplasty; PTRA/RAB = PTRA followed by RAB if PTRA is unsuccessful.

yet another Markov process. If the PTRA is unsuccessful the patient will undergo RAB.

At this point in the decision tree three branches are enclosed by a bracket (labeled surgery). This portion of the decision tree models the short-term events associated with RAB. The chance node in this "subtree" depicts the chance of death, dialysis, or successful RAB. Long-term prognosis is again determined by using one of several Markov models.

There are several different Markov models, each of the form shown in Figure 2 but having different starting states and transition probabilities. The "state of the world" is depicted as a series of health states (denoted in six rectangles at the left edge of Figure 2). For each path through the decision tree (see Figure 1), a cohort of patients enters a Markov model in a specific health state. For example, patients assigned to the medical therapy strategy are entered in the Markov model in the health state labeled well on medicine while patients who have had a successful PTRA are entered in the health state labeled status post PTRA.

As each simulated month passes, patients go from one health state to another, with the likelihood of such changes in health state determined by the transition probabilities of the modeled events. The state at the beginning of each month is depicted by the rectangle at the left in Figure 2; the state at the end of each month is depicted by the rectangles on the right. After each simulated month, the Markov model checks the health state distribution of the cohort of patients. The Markov process is continued until all patients have moved to the state labeled dead. The sum of the number of months the cohort experiences outside the "dead" state is the life expectancy.

In addition to the health states, Figure 2 depicts the filter, or probability tree, that redistributes the cohort each month to new health states. Patients in the first four health states on the left (enclosed by a bracket) are subject to the same events. These four states differ, however, in the probability of those events.

After the bracket, the first circular node depicts the chance of dying of general causes (as a function of age, sex, or race) or disease-specific processes related to arteriosclerotic vascular disease or hypertension. Patients who die move into the "dead" state (see the rectangular node at the end of each branch modeling death). The next chance node depicts the possibility of dialysis as a result of complete renal artery occlusion. If death or dialysis does not occur during a given cycle, patients remain in the same state of health (labeled beginning state). Once in the "dialysis" state, patients either die of
general causes or causes related to dialysis or they remain in the "dialysis" state.

**Probabilities and Rates Used in the Analysis**

Table 1 lists the probabilities and rates used in the analysis. The probabilities determined by our expert consultants, the range of estimates derived from literature sources, and the baseline values used are included. In general, the baseline value reflects our assessment of the relative accuracy of the data and the unique circumstances of our patient. For example, the best available literature suggests that complete renal artery occlusion in patients treated medically occurs at a rate of 0.034 per year. However, our expert consultants thought that in this patient the progression to complete occlusion would be three to four times more rapid because of underlying renal insufficiency. Therefore, we used 0.12 per year in our baseline analysis.

**Utility Values Used in the Analysis**

In this analysis, the outcome of each strategy is measured in terms of quality-adjusted months of survival. This scale addresses both longevity and quality of life (utility). As life expectancy in months is calculated by the Markov process, it is adjusted for the loss of quality experienced by the patient with each strategy. Quality of life is diminished by reduced functional capabilities in both the short and long term. Table 2 lists the baseline short-term and long-term quality-of-life adjustments used in the analysis.

Short-term quality adjustments occur, for example, during technological procedures or during diminished states of health that result as side effects of these procedures. For example, RAB involves 2 weeks of hospitalization; a short-term quality-of-life decrement is assessed for those 2 weeks. Long-term quality of life refers to the global state of well-being that is experienced with every day of future life.

In this analysis the patient will suffer short-term quality-of-life decrements when she undergoes catheterization, PTRA, or RAB. During the month in which the procedures are performed, quality of life is diminished in proportion to the time required for hospitalization. For example, since catheterization alone or catheterization and angioplasty require approximately 1 week of hospitalization, a patient undergoing either of these procedures will be allotted 3 weeks at full quality (1.0) and 1 week at 0 quality during the month of the procedure. The overall quality of life for that month, then, is the average: 0.75. Because RAB requires 2 weeks of hospitalization, a patient undergoing RAB receives credit for only 0.5 of the month. These assumptions use time in the hospital at zero quality as a proxy for morbidity in the hospital and during the postdischarge recovery period, thereby somewhat overestimating the quality loss associated with a procedure.

A long-term quality adjustment is made for being on dialysis. The quality of life in the "well" state is 1.0 and the quality of life in the "dead" state is 0. If dialysis becomes necessary, the quality of the remainder of the patient's life is diminished. Our patient thought that dialysis would be a catastrophe and worth only one half of a full-quality life. The quality of life for each month on dialysis, then, is 0.5. For example, if our patient lives 10 years while on dialysis the quality-adjusted life expectancy would be 5 years (10 years times 0.5).

**Results of the Baseline Analysis**

The baseline analysis revealed the following expected utility values in terms of quality-adjusted months of survival.
TABLE 1. Probabilities and Rates Used in the Analysis

<table>
<thead>
<tr>
<th>Variable</th>
<th>Expert opinion</th>
<th>Literature range</th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Probabilities</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Catheterization-related</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dye-induced death</td>
<td>0.0002</td>
<td>—</td>
<td>0.0002</td>
</tr>
<tr>
<td>Dye-induced dialysis</td>
<td>0.001</td>
<td>0.015-0.032; 6</td>
<td>0.01</td>
</tr>
<tr>
<td>Surgically bypassable</td>
<td>0.95</td>
<td>—</td>
<td>0.95</td>
</tr>
<tr>
<td>Amenable to angioplasty</td>
<td>0.85</td>
<td>0.57-0.92; 7, 8</td>
<td>0.85</td>
</tr>
<tr>
<td>PTRA-related</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Death</td>
<td>0.01</td>
<td>0-0.01; 9</td>
<td>0.01</td>
</tr>
<tr>
<td>Dialysis</td>
<td>0.001</td>
<td>0.015-0.30; 7, 9, 10</td>
<td>0.03</td>
</tr>
<tr>
<td>Occlusion</td>
<td>0.05</td>
<td>0.05-0.10; 9, 11, 12</td>
<td>0.05</td>
</tr>
<tr>
<td>Technical success</td>
<td>0.8</td>
<td>0.70-1.0; 12, 14</td>
<td>0.8</td>
</tr>
<tr>
<td>RAB-related*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Death</td>
<td>0.05</td>
<td>0.01-0.13; 21</td>
<td>0.05</td>
</tr>
<tr>
<td>Technical success</td>
<td>0.7</td>
<td>0.79-0.98; 14, 17, 20-22</td>
<td>0.85</td>
</tr>
<tr>
<td><strong>Rates (annual)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mortality</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>—</td>
<td>—</td>
<td>0.043†</td>
</tr>
<tr>
<td>Excess for vascular disease</td>
<td>0.08</td>
<td>0.08-0.16; 24</td>
<td>0.1†</td>
</tr>
<tr>
<td>Excess for dialysis</td>
<td>0.1</td>
<td>0.10-0.23</td>
<td>0.1§</td>
</tr>
<tr>
<td>Dialysis (complete occlusion)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With medical therapy</td>
<td>0.12</td>
<td>0.034; 26</td>
<td>0.12</td>
</tr>
<tr>
<td>With angioplasty</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 1</td>
<td>0.1</td>
<td>0.12-0.21; 8, 12</td>
<td>0.1</td>
</tr>
<tr>
<td>Year 2</td>
<td>0.03</td>
<td>—</td>
<td>0.03</td>
</tr>
<tr>
<td>2 years</td>
<td>0.01</td>
<td>—</td>
<td>0.01</td>
</tr>
<tr>
<td>With surgical bypass</td>
<td>0.01</td>
<td>0.004-0.011; 4, 7</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Values for dialysis represent rate of renal artery occlusion. PTRA = percutaneous transluminal renal angioplasty; RAB = renal artery bypass.

*The probabilities of death and technical success for RAB are altered in an emergent situation caused by sudden arterial occlusion during PTRA. The probabilities of death and dialysis are increased by a factor of 1.5. The probability of technical success is decreased by a factor of 0.75. These adjustment factors were defined by expert opinion and the literature.

†Related to patient's age, sex, and race and calculated from standard tables of vital statistics by taking the reciprocal of the life expectancy.

‡The excess (i.e., increased) annual mortality rate for arteriosclerotic vascular disease is increased by a factor of 2.3 in patients whose lesions are not bypassable. The baseline increased relative risk for this analysis is 2.

§We have lowered the excess death rate for vascular disease in patients on dialysis to avoid double counting of excess death rates in dialyzed patients. The excess death rate for vascular disease in dialyzed patients is decreased from its baseline level of 0.1 to 0.04.

Medical therapy  59.7 mo  
RAB  75.9 mo  
PTRA/RAB  81.7 mo

The strategy involving PTRA gives the greatest expected survival. Performing a PTRA followed by a RAB in those patients who have an unsuccessful dilatation (PTRA/RAB) results in an additional 5.8 months of quality-adjusted survival beyond that expected from performing RAB initially. To be sure, all of the operative strategies have greater expected utility values than the medical therapy alternative. The driving force in the difference is the projected rapid rate of renal artery occlusion with medical therapy for our patient.

**Sensitivity Analysis**

Sensitivity analysis provides a tool for addressing the uncertainty of medical problems. By varying the probabilities, rates of occlusion, and utility values we can assess how such variations might affect the decision. In this analysis there are numerous variables. Space limits our ability to examine each, but the sensitivity analyses of certain key variables are included here.

A one-way sensitivity analysis looks at the effect of varying a single variable while holding all others constant. Figure 3 is a graphic representation of a one-way sensitivity analysis of the yearly rate of complete renal artery occlusion during medical therapy. Each line represents a different strategy. As the yearly rate of complete renal artery occlusion increases, the expected utility value (quality-adjusted life expectancy in months) of each strategy decreases because in each strategy some patients are treated medically (i.e., some patients are not candidates for PTRA or RAB). The line representing medical therapy falls most rapidly because with that strategy all patients are subject to complete renal artery occlusion.

In this graph, if the rate of complete occlusion is 0, the medical therapy strategy gives the greatest expected utility value. However, as the rate of complete occlusion increases, the strategy of choice changes. The lines representing medical therapy and PTRA/RAB cross at a point called the thresh-
### Table 2. Utility Values Used in the Analysis

<table>
<thead>
<tr>
<th>Quality-of-life adjustment</th>
<th>Utility value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-term</td>
<td></td>
</tr>
<tr>
<td>Well on medical therapy</td>
<td>1.0*</td>
</tr>
<tr>
<td>Well after RAB</td>
<td>1.0</td>
</tr>
<tr>
<td>Well after PTRA</td>
<td>1.0</td>
</tr>
<tr>
<td>Dialysis</td>
<td>0.57</td>
</tr>
<tr>
<td>Dead</td>
<td>0.0</td>
</tr>
<tr>
<td>Short-term</td>
<td></td>
</tr>
<tr>
<td>Catheterization</td>
<td>0.75</td>
</tr>
<tr>
<td>Catheterization and PTRA</td>
<td>0.75</td>
</tr>
<tr>
<td>RAB</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Long-term quality adjustments represent the overall quality of life experienced by patients in a given health state during each day of remaining life. Short-term quality adjustments occur only during the month in which a procedure is performed. The values 0.75 and 0.5 refer to the proportion of the month during which a given procedure is performed for which full quality of life is projected. RAB = renal artery bypass; PTRA = percutaneous transluminal renal angioplasty.

*All well states receive a baseline quality of life of 1.0 because no decrement is assessed for taking medication.

+This value was assigned by the patient.

The utility values in Table 2 are used to calculate the expected utility value of each strategy. The expected utility value is the weighted average of the quality-of-life adjustment values for each health state, weighted by the probability of being in that health state.

**old rate** for these two strategies. At this rate the expected utility values of the two strategies are the same. Below 0.02/yr medical therapy is preferred, and above this threshold rate PTRA/RAB is preferable. The baseline value of 0.12/year is clearly above the threshold value of 0.02/year, so PTRA/RAB is best. It should be noted that PTRA/RAB is always preferred over RAB in this analysis. This one-way sensitivity analysis shows, then, how the strategy hierarchy changes as the yearly rate of complete renal artery occlusion varies.

Figure 4 is a one-way sensitivity analysis of the utility, or quality of life, with dialysis. Intuitively, if a patient did not view being on dialysis as decreasing the quality of life, the operative strategies become relatively less advantageous because the main rationale for intervention is to protect renal function. In Figure 4, as the utility of the dialysis state increases, the expected utility values of all strategies increase, although at different rates. Notice, there is no threshold utility value. When the utility value of the dialysis state is 1.0, the absolute difference in terms of quality-adjusted months of life expectancy between the strategies is less but the hierarchy of strategies remains the same. Therefore, the patient's view of the quality of life associated with dialysis does not alter the optimal approach.

In addition to a one-way sensitivity analysis, the effect of varying two or three parameters simultaneously can be assessed. These sensitivity analyses are called, respectively, two-way and three-way sensitivity analyses.

Figure 4 is an example of a two-way sensitivity analysis varying the probability of dialysis as a complication of PTRA and the yearly rate of complete renal artery occlusion following a PTRA. Because the yearly rate of complete occlusion varies from year to year following PTRA, we multiplied each annual rate by the same factor to maintain the relationship between the yearly rates. The baseline multiplier is 1.0, corresponding to the yearly rates of 0.1 for the first year, 0.03 for the second year, and 0.01 for all subsequent years. If the multiplier were 2, the yearly rates would be 0.2 for the first year, 0.06 for the second year, and 0.02 for all subsequent years.

The diagonal line in Figure 5 creates two regions. Each region corresponds to those combinations of the probability of dialysis as a complication of PTRA and the multiplier for the yearly rate of complete occlusion for which a specific strategy is preferred.

**Figure 3.** One-way sensitivity analysis of the rate of complete renal artery occlusion after medical therapy. If the rate is less than 0.02 per year medical therapy (MED) is preferable. Above 0.02 per year, percutaneous transluminal renal angioplasty (PTRA) followed by renal artery bypass (PTRA/RAB) is preferable. The baseline value is shown.

**Figure 4.** One-way sensitivity analysis of the utility value for being on dialysis. As the utility value increases, the quality-adjusted life expectancy of each strategy increases. However, since no threshold utility value exists, the utility value placed on dialysis does not change the decision of choice. MED = medical therapy, RAB = renal artery bypass, and PTRA/RAB = percutaneous transluminal renal angioplasty followed by RAB.
The two strategies being compared are PTRA/RAB and RAB. Combinations of parameters falling in the shaded region above the diagonal line favor RAB and those falling below the line favor PTRA/RAB. The baseline value, denoted by an x, falls well within the PTRA/RAB region. Notice, at our baseline value for the multiplier for the yearly rate of occlusion following PTRA (1.0), the probability of dialysis during PTRA would have to be greater than 0.15 before RAB is preferable.

Figure 6 is a two-way analysis of the relationship between the rate of complete renal artery occlusion following RAB and the probability of technical success with PTRA. Again, the comparison is between the PTRA/RAB strategy and the RAB strategy. If the probability of technical success with PTRA is great and the rate of complete occlusion following RAB is also great, the best strategy is to perform a PTRA/RAB. If the probability of technical success with PTRA is low enough, then, depending on the rate of complete occlusion after RAB, RAB may become the preferred strategy. It is conceivable that if the chance of technical success with the PTRA is low enough while the rate of renal artery occlusion after RAB is high, then medical therapy would be the preferred option. The values at which this would occur, however, are far outside the range of probabilities reported in the literature and hence are not included on this graph. The baseline values for both variables are denoted by the x. They fall comfortably in the PTRA/RAB region.

Conclusions of the Decision Analysis

In this patient with renovascular hypertension, a solitary kidney, and renal insufficiency, it is best to attempt a percutaneous angioplasty. If that fails, then RAB should be performed. Operative strategies dominate the medical therapy alternative because of the rapid rate of complete renal artery occlusion presumed for this patient. The trade-off between procedure-related risk and protection from dialysis favors the latter.

Surprisingly, the analysis was not sensitive to the utility of the dialysis state. We originally thought that the patient’s perception of the quality of life on dialysis would be a significant factor in the decision to recommend the more aggressive surgical strategies. However, no threshold value was found. The surgical strategies, if successful, not only protect the patient from the poor quality of life associated with dialysis, but they also protect the patient from the excess (i.e., increased) death rate associated with being on dialysis.

In the two-way analyses presented, we focused on the PTRA/RAB and RAB strategies. The insight gained from these analyses is that PTRA/RAB remains the strategy of choice over reasonable ranges of probabilities and rates. In general, RAB becomes the strategy of choice only at values
significantly outside the published and expert opinion ranges, except for the probability of dialysis as a complication of PTRA. The threshold probability for that complication is 0.15. Values above that level have been reported in the literature (as great as 0.3)5-7,9,10 Our experts felt, however, that the probability of PTRA-related dialysis in this patient was extremely low.

**Patient Follow-up**

The conclusions of the decision analysis were discussed with the patient. She was reluctant to undergo any further intervention and chose medical therapy, although she was aware of the possibility of further decline in her renal function. Her blood pressure was adequately controlled. Eight months later, because of further increases in her blood pressure, a renal arteriogram was performed and showed 99% stenosis of the left renal artery. A PTRA was performed with only minimal success. Her blood pressure initially improved, but she was readmitted 1 month later with left flank pain and a fall in hematocrit. It was thought that she probably had experienced slight retroperitoneal bleeding at the time of the angioplasty. With hydration, her renal function improved (serum creatinine fell to 3.4 mg/dl), and she was discharged. Over the next 2 months, however, serum creatinine rose to 5.5 mg/dl. She was readmitted 3 months after the angioplasty and underwent a successful left-sided RAB graft and a bilateral aortofemoral bypass graft.

She experienced some mild postoperative acute tubular necrosis; serum creatinine rose to 6.4 mg/dl and subsequently fell to a baseline of 4 mg/dl. After doing well for 5 months, she was rehospitalized with upper gastrointestinal bleeding. During that admission the level of serum creatinine rose again. A repeat renal arteriogram revealed stenosis of the left-sided RAB graft. Repeat angioplasty of the graft stenosis produced minimal improvement.

She subsequently was readmitted in early 1987 with a serum creatinine level of 9.0 mg/dl, a blood urea nitrogen of 122 mg/dl, and symptoms of uremia. Chronic hemodialysis was initiated through a permanent arteriovenous fistula.

**Discussion**

Renovascular hypertension is one of the more common forms of secondary hypertension. It only occurs in approximately 1% of patients with hypertension, but when viewed in the context of the high prevalence of hypertension in our society, the number of patients with renovascular disease is impressive. Much debate and controversy has centered around the proper evaluation of and therapy for these patients. Therapy usually is aimed both at control of blood pressure and preservation of renal function. Traditionally, once it had been determined that a patient had renovascular hypertension, the decision was between medical and surgical therapy. Early studies showed that patients treated surgically had a better survival,3,4,16 but these studies were not randomized; selection bias meant that sicker patients were more often treated medically. In recent years, PTRA has provided a new alternative for treating patients with renovascular hypertension.5,7,8,11 Once again, however, we lack randomized prospective studies to compare the long-term benefits and risks of angioplasty to either medical management or surgical intervention.

In the absence of adequate studies comparing various therapeutic options, how is a clinician to make the optimal decision for the patient whose disease is complicated? Clinical decision analysis helps put the problem in better perspective.

This analysis sought to determine the optimal way to preserve renal function. We assumed that, regardless of the therapeutic option chosen, blood pressure could be adequately controlled. We constructed a decision tree to examine a limited set of alternatives: medical therapy, RAB, or PTRA followed by RAB if the angioplasty failed. Other options, such as repeat angioplasties, were not considered. We considered the major variables that, as clinicians, we viewed as being important in decision making, such as the morbidity and mortality associated with the procedures, the likely success rates for the procedures, the morbidity and mortality associated with dialysis, and the patient’s attitudes toward quality of life on dialysis.

This model illustrates the use of the Markov process or state transition models that estimate prognosis by recording the movement of patients in one state of health to another state of health. The process examines the distribution of health states for a set of patients over time, and continues until all simulated patients have died. By looking at the sequence of health states encountered over time, the model allows us to calculate life expectancy for the different strategies. This type of model provides insight into clinical disorders such as renovascular hypertension that evolve over time.

As clinicians, we are concerned about our patients’ attitudes toward the various tests and procedures we order. Our model also incorporates our patients’ views on the quality of life on dialysis. The ability to incorporate quality-of-life assessments is an important part of analytic models used in clinical decision making.

As can be seen from the original calculations in our model, the optimal therapy appears to be PTRA followed by RAB if the angioplasty fails. Because the model was constructed using many variables, a questioning observer might ask what the outcome would be if a particular factor was different from what we had assumed. This type of questioning is addressed by sensitivity analysis in which we ask what would happen if any one or more of these variables were altered. Sensitivity analysis looks at such variations in a systematic fashion and determines whether the optimal clinical choice might change. For example, we varied the rate of total...
renal artery occlusion during medical therapy. In this one-way sensitivity analysis the concept of a threshold emerges: The choice of strategies changes as the rate of renal artery occlusion varies. We also examined the quality of life experienced on dialysis. We had thought that the patient’s view of her quality of life on dialysis would have a major impact on the selection of the optimal clinical strategy. However, sensitivity analysis revealed that regardless of the utility of life on dialysis, the ranking of the various strategies was unchanged. The subsequent sensitivity analyses looked at the effects of varying two parameters: the probability of dialysis after PTRA and the rate of total renal artery occlusion after PTRA.

We must remember that this model was constructed for a patient with a solitary kidney and hence is not intended for simple extrapolation to other patients with renovascular hypertension. In this patient, if the remaining renal artery were to occlude, then end-stage renal disease would result and long-term dialysis would be necessary. For patients with two kidneys, the basic model would have to be modified because the occlusion of one renal artery would not preclude the possibility of continued medical treatment.

In summary, we have tried to show how decision analysis can provide valuable help in the management of patients with complicated renovascular hypertension. This approach offers systematic consideration of many important variables and therapeutic options. It allows us to assess the decision-making process logically and quantitatively, and possibly avoid some errors that intuitive clinical judgment might foster. We believe that decision analysis may be an important starting point for determining the optimal therapeutic approach for patients with renovascular hypertension.

References

10. Schwarten DE. Transluminal angioplasty of renal artery stenosis: 70 experiences. AJR 1986;146:969–974
Use of decision analysis in a complicated case of renovascular hypertension.
R I Kopelman, R A McNutt and S G Pauker

Hypertension. 1988;12:611-619
doi: 10.1161/01.HYP.12.6.611

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://hyper.ahajournals.org/content/12/6/611.citation