Decision analysis to estimate cost effectiveness in neurosurgery

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Medical decisions often depend, in part, on cost-effectiveness concerns. Decision analysis is frequently used to help resolve these questions. Unfortunately, this technique has received little attention in neurosurgery. Using an example of moderate head injury, the authors illustrate the utility of this powerful tool in estimating the cost effectiveness of neurosurgical management options.

KEY WORDS • decision support technique • decision analysis • cost effectiveness • computerized tomography • head injury

Decision analysis, originally introduced as an economic tool, has been used as an adjunct in medical decision making since the 1970s.^{27,39} The technique is especially effective when considerations of cost are among the determining factors in a medical choice.^{28,32}

In neurosurgery decision analysis has been very useful for example, in comparing management strategies in cases of unruptured intracranial arteriovenous malformations. In 1989, Fisher¹² expanded on earlier predictive models. In his article, entitled "Decision analysis: a tool of the future: an application to unruptured arteriovenous malformations," he compared surgery with the natural history of the disease in a hypothetical 25-year-old man. In subsequent publications by him¹³ and others^{4,18} this theme became increasingly sophisticated and applicable.

The demand for evidence-based practice guidelines, increased government regulation, and limitations imposed by managed care have put pressure on those involved in the medical profession to choose among the many management strategies available for a given illness in a given patient. Financial constraints and the desire for optimum use of limited resources have become aspects of treatment decisions. The choices are rarely obvious, and the evidence to support them is often not organized in sufficient detail.

Decision analysis is being performed with increasing frequency to help simplify difficult medical choices, particularly in the area of cost containment. Publications in the medical literature reflect this remarkable growth.^{1-3,5,7,9,15,16,19,22,25,26,31,33,34,37,38,44} Unfortunately, relatively few recent publications have been written on topics of concern to those involved with neurosurgery,^{17,20,36,41,45} and none has dealt with cost. We wrote this article to address a recent cost-effectiveness question and in hopes of rekindling neurosurgery-related interest in this powerful technique.

CLINICAL MATERIAL AND METHODS

Decision analysis creates a mathematical model that simulates a clinical trial. As most commonly modeled, the "cohort" of patients moves through a sequence of clinical states through Markov modeling, in which a finite series of possible conditions and transitions is defined, specified, and often displayed as a decision tree. The cohort members "transition" from one Markov state to another at discrete intervals. The chain of transitions between states is established using probabilities determined after review of the literature or through independent research. Calculated outcomes are based on some numerical value such as cost, quality, and risk-adjusted life years. The process of decision analysis allows for direct comparison of different diagnostic or therapeutic strategies, and it aids in deciding which approach is optimum in a particular case.

The procedure by which one performs decision analysis

Abbreviations used in this paper: CT = computerized tomography; ICU = intensive care unit; PRN = as needed.

is best illustrated using an example—in this instance, a question recently addressed to the authors. The Trauma Service at the University of Pennsylvania, as a routine practice, obtains admission head CT scans in all patients who have sustained moderate closed head injury (Glasgow Coma Scale scores 9–13). Those who harbor intracranial lesions either undergo surgery or are observed in the ICU. Over the next 12 to 24 hours (the morning after admission), patients in whom neither deterioration nor recovery to a Glasgow Coma Scale score of 14 or 15 occurs (“gray-zone” patients) undergo a second CT study. The question posed is which of two approaches is more cost effective: 1) to continue to observe these gray-zone patients in the ICU and reserve the second CT study for those who experience clinical deterioration (PRN CT scanning), or 2) to perform routine serial scanning in all, keeping those in whom CT scans have demonstrated deterioration in the ICU and transferring the others to receive less expensive floor care (serial CT scanning).

Software is available to construct decision analyses, perform calculations, and construct the requisite decision trees, graphs, and tables. We approached this relatively simple problem by using only standard computer calculator and drawing programs.

RESULTS

Data for the primary (baseline case) calculations were obtained from the literature and directly from the hospital billing department. Additional charge-related information was obtained from a 1996 poll conducted by one of the authors (S.C.S.) of five Level 1 trauma centers (Cooper Hospital, Camden, NJ; Johns Hopkins Bayview Medical Center, Baltimore, MD; Loma Linda University Medical Center, Loma Linda, CA; University of Michigan Hospital, Ann Arbor, MI; and Wilford Hall Air Force Hospital, Lackland Air Force Base, TX). In a review of the literature we found a single report in which the author studied short-term outcomes in moderate head injury by assessing routine CT scans.⁴² The author of this study provided adequate data from which to calculate probabilities. These baseline values and the probabilities calculated from them are shown in Table 1.

A number of simplifying assumptions were made. The analysis only covers the day following admission, as detailed day-by-day outcome data are not available for this patient group. No additional fee is added for CT scans obtained in patients in whom deterioration is evidenced, although some hospitals incur greater costs and charge more for urgent and emergency scans. No penalty is assessed for missing a worsening intracranial lesion (such as an accumulating hematoma) until clinical deterioration has occurred.

A decision tree was constructed, incorporating the two management choices, the proportions of patients with resulting outcomes, and the cost of each possible outcome (Fig. 1). The mean per-patient charges can then readily be calculated from the following formulae. For routine serial CT scanning, scans demonstrated stable condition in 58% and patients can be transferred to floor care (cost: CT scan + floor bed); scans demonstrated worsened condition in 42% and patients must remain in the ICU (cost: CT scan + ICU bed). For PRN CT scanning, 87% do well

TABLE 1
Baseline values and probabilities used in decision analysis

Variable	Value
gray-area patients (%) [*]	
2nd demonstrates worse status than admission CT	42%
patient requires op &/or deteriorates after 2nd CT	13%
2nd CT demonstrates stable or improved status	58%
patient requires op &/or deteriorates after 2nd CT has demonstrated stable status	0%
hospital charges (\$)†	
ICU care	2152.00
floor care	1360.00
unenhanced cranial CT scan	748.00
hospital charges (\$)‡	
ICU care	1963.17
floor care	778.67
unenhanced cranial CT scan	590.60

^{*} Data derived from report published by Stein.

[†] Data derived from the Hospital of the University of Pennsylvania (2001).

[‡] Data derived from a five-hospital survey (see *Results*).

(cost: ICU bed alone) whereas the condition deteriorates in 13% and patients require urgent CT scanning (cost: CT scan + ICU bed). Actual charges can be substituted into these formulae to calculate relative costs of the two approaches. For the baseline case (Hospital of the University of Pennsylvania, 2001) the mean per-patient cost for a routine serial scan is $(\$2108 \times 0.58) + (\$2900 \times 0.42)$, or \$2440.64, and the mean cost for routine ICU care is $(\$2152 \times 0.87) + (\$2900 \times 0.13)$, or \$2249.24. Thus, the simple answer to our question is that the use of CT scanning to triage gray-area patients is not cost effective.

Fig. 1. Decision tree illustrating management choices for “gray-area” patients in clinical example. The various branches represent different decisions or chance outcomes. The percentages denote the calculated probability of each outcome. For each outcome, the components of costs are listed.

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These calculations do not take into account the variability of the data on which they are based. Furthermore, because of the disparate populations from which they are derived, the data are not amenable to reliable statistical analysis. Hence, decision analysis must approach uncertainty another way—that is, through the use of sensitivity analysis. Sensitivity analysis examines the stability of the conclusions when one or more of the underlying parameters are varied by using a wide range of plausible values. In our example, it is intuitively obvious that the total costs are quite sensitive to the relative charges for the three items. If we substitute the values specified in the 1996 survey (Table 1) in the formula, then the cost for routine serial scanning is only \$1866.76, somewhat less than the \$2039.95 needed for PRN CT scanning.

The results of sensitivity analysis can be displayed graphically. Figure 2 illustrates the effect of varying the charge for CT scanning in the baseline case. It is clear that this has a much greater effect on the mean per-patient cost of the serial CT option. This is a one-way (one-parameter varied) sensitivity analysis. It can also be observed that, if other charges are constant, serial CT scanning is

the more cost-effective strategy when the charge for a scan is below \$528.

A two-way sensitivity analysis allows us to vary two parameters. This may permit greater generalization and robustness of the analysis. For example, the graph in Fig. 3 illustrates a two-way sensitivity analysis. Here the daily charges for hospital and ICU beds are expressed as multiples of the charge for a CT scan. Because the financial units have the same base, the model applies equally to relative charges and costs. As is illustrated graphically, whenever the cost (or the charge) of an ICU bed exceeds that of a hospital bed by at least 1.5 times the cost (or charge) of obtaining a CT study, routine serial CT scanning is the more cost-effective strategy.

In three-way sensitivity analysis the robustness of the model is further tested. For example, it could be argued that a delayed deterioration rate of 13% used in the study is based on a small series of patients and could be inadequate. As is demonstrated in Fig. 4, however, decisions based on the model remain quite stable under much higher or lower rates. Hence, within the plausible range, the delayed deterioration rate has little effect on costs.

DISCUSSION

As the example demonstrates, it is possible to use decision analysis to resolve questions of cost effectiveness. Not only can the model be used to determine which of the

Fig. 2. One-way sensitivity analysis demonstrating the effect of the cost of a CT scan on the comparative costs of two management strategies in the baseline case.

Fig. 3. Two-way sensitivity analysis showing the relationship between costs of bed and CT scan. The plotted line represents the threshold at which the cost effectiveness of the two strategies is the same. This analysis can be applied to any setting in which either costs or charges are known.

Fig. 4. Three-way sensitivity analysis demonstrating the relationship between costs of bed and CT scan, as well as the effect of varying the rate of delayed deterioration. The three *isobars* represent the thresholds at which the cost effectiveness of the two strategies are the same. As the risk of delayed deterioration rises, the value of routine CT scanning improves. The effect of varying deterioration rate, however, is small.

two suggested strategies costs less under the specified charges, it can be adapted to make the determination under any combination of charges or costs. The finding that routine serial CT scanning is useful under a particular set of circumstances contradicts conventional thinking in neurosurgical practice.^{6,8,14,21,23,24,35,40}

It must be stressed that our simplified example may give the impression that decision analysis is a technique easily adapted to all clinical situations. In the example it is assumed that the outcomes of the two management strategies are the same, even though a proportion of patients in whom hematomas are not diagnosed before deterioration has occurred may suffer harm.²⁹ Because efficacy often varies among alternative treatment plans, complex calculations are often necessary to compare the “effectiveness” aspect of a cost-effectiveness study.³⁰ There are no calculations for costs beyond the 1 day in the scenario. We used charges rather than costs, as the latter are usually difficult to obtain. Of note, the model is equally valid for both. No account is taken of other, possibly important, measures of utility. For example, if the number of ICU beds is especially limited it may be necessary to factor in a premium for freeing up these beds to be occupied by other patients in need. When a clinical decision must take into account factors such as patient preference, multiple iterations involving several sequential choices or time intervals, and

outcome measures, including quality- and risk-adjusted life years, calculations may become exceedingly complex.

Additionally, the conclusions obtained using decision analysis are not universally accepted. Critics have contended that there are a number of shortcomings associated with the technique, including its tendencies to define problems too narrowly, to be too removed from clinical situations, and to be too time-consuming and complex. As is the case in other approaches to decision making, it is limited by a lack of high-quality data and a gold standard for utility. Some critics have asserted that decision analysis is used to replace clinical judgment, thus dehumanizing patient care. Its emphasis on the consequences of decisions as the goal, however, has even been questioned.¹⁰

Nevertheless, decision analysis remains a powerful tool with which to clarify clinical options. The process is systematic, explicit, and transparent. It can be used to attempt to give appropriate weight to both empirical data and patient preferences. The decision analysis process cannot replace a well-designed, well-controlled, multicenter randomized trial or a careful metaanalysis of such trials. It can, however, put the results of trials in a quantitative context so that they can be used in decision making. It can also serve as a surrogate for controlled trials in the many cases in which they have yet to be performed. It can even be used to assist in the planning of well-designed clinical trials. There are several recent discussions of the advantages and disadvantages of decision analysis in the context of patient care.^{11,43,46}

Perhaps the characterization offered by Fisher¹² of decision analysis as “a tool of the future,” was a bit optimistic. He was, however, quite correct in pointing out its utility for addressing neurosurgery-related problems. The purpose of this paper is to stress that the benefits of decision analysis include neurosurgical judgments with socioeconomic implications.

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