Decision Analysis and Markov Modeling in Urology

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Purpose: The process of decision making in medicine has become increasingly complex. This has developed as the result of increasing amounts of data, often without direct information or answers regarding a specific clinical problem. The use of mathematical models has grown and they are commonly used in all areas. We describe and discuss the application of decision analysis and Markov modeling in urology.

Materials and Methods: We define decision analysis and Markov models, providing a background and primer to educate the urologist. In addition, we performed a complete MEDLINE® database search for all decision analyses in all disciplines of urology, serving as a reference summarizing the current status of the literature.

Results: The review provides urologists with the ability to critically evaluate studies involving decision analysis and Markov models. We identified 107 publications using decision analysis or Markov modeling in urology. A total of 36 studies used Markov models, whereas the remainder used standard decision analytical models. All areas of urology, including oncology, pediatrics, andrology, endourology, reconstruction, transplantation and erectile dysfunction, were represented.

Conclusions: Decision analysis and Markov modeling are widely used approaches in the urological literature. Understanding the fundamentals of these tools is critical to the practicing urologist.

Key Words: urology, decision support techniques, Markov chains

Decision making in medicine has become increasingly complex for patients and practitioners. This has resulted from factors such as the shift away from physician authority toward shared decision making, unfiltered information on the Internet, new technology providing additional data, numerous treatment options with associated risks and benefits, and results from new clinical studies. Despite the plethora of information, synthesizing this into practical knowledge can be difficult. In addition, while well designed trials are performed in many clinical scenarios, often these studies are difficult to compare with each other and they ultimately do not directly answer basic questions.

Consequently medical care has evolved toward an evidence based approach. Decision making tools, such as nomograms, and computer based models and algorithms, have been developed. In urology the most popular applications have been predicting outcomes after treatment, eg the Kattan model for prostate cancer. We discuss DA and MM, and their application to urology, serving as a primer and reference for the urological community. We believe that these are powerful methods of assessing treatment choices and they will have an increasingly important role in medicine.

HISTORICAL AND CONTEMPORARY PERSPECTIVE

DA is a systematic, quantitative approach to decision making, in which the relative values of different options are compared and uncertainty exists within the system. It has origins in game theory and it was initially applied to economics and negotiations, as illustrated by the Prisoner's Dilemma game and the Cold War politics of nuclear strategy. It has been disseminated in diverse fields, such as oil exploration, law and engineering. The goals in these situations as well as in medicine are to use available information to maximize outcomes. The process is designed to help decision makers think clearly about the numerous elements of complex choices, such as the range of possible consequences of action or inaction, preferences among different consequences and the impact of unpredictable processes. DA can be used in clinical scenarios in which clinical trials are unethical or difficult to perform. When trials are available, DA can extend their findings to issues such as cost-effectiveness.

The first published application of DA to a clinical problem addressed the role of radical neck dissection in patients with oral cancer without palpable neck metastases.[1] In urology early studies examined issues of screening and treatment for prostate cancer, and management of benign prostatic disease.[2,3] Information from DA can be used to determine how to treat an individual patient and formulate policy recommendations regarding a group of patients, and as an aid for patients making decisions about therapies.

THE DA PROCESS

Medical DA consists of 5 basic steps (Appendix 1). 1) The clinical problem is identified. 2) The problem is disaggregated and structured as a decision tree. This graphic representation depicts the components of the problem and relates action to consequences. 3) Information needed to populate the decision tree is gathered from published literature, primary data collec-

Submitted for publication December 14, 2006.

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0022-5347/07/1785-1867/0
THE JOURNAL OF UROLOGY®
Vol. 178, 1867-1874, November 2007
Printed in U.S.A.
DOI:10.1016/j.juro.2007.07.006

tion and/or expert opinion. 4) The model is analyzed using baseline information by calculating EV, that is the net values of the series of actions and events. 5) Sensitivity analysis is performed, in which parameter values are varied across ranges to determine their effect on the model.

DECISION TREE DESIGN

Several conventions are used for decision trees (Appendix 2). The tree is organized from left to right and it consists of nodes, branches and outcomes (fig. 1, *A*). A decision node (square) is a branch point where several options are available to the decision maker. A chance node (circle) is a branch point where several outcomes are possible but not controlled by the decision maker. Probabilities are associated with the events depicted at chance nodes. At any given chance node the sum of the various probabilities typically equals 100% to reflect all possible outcomes. Branches connect nodes to nodes or nodes to outcomes. Outcomes are the consequences of the final events depicted in the tree. Every outcome state is associated with payoffs, which are used to calculate the EV of each branch of the decision tree. Payoffs can be assessed using costs, specific clinical end points, QOL measures and life expectancy.

ANALYZING THE DECISION TREE

The determination of the best treatment choice is based on Bayes' decision rule, in which the action that maximizes EV is selected. Calculating the EV of each treatment, ie options at the decision node, is called folding back or rolling back the decision tree. For each branch at the decision node an EV represents the weighted average of the payoffs of the possible outcomes. These values for each choice are compared with a greater value reflecting a better outcome. Figure 1, *B* shows 2 treatment options at the decision node, including OP and RAP. In this example the relevant outcome is surgical margin status with negative and positive assigned payoffs of 1.0 and 0, respectively. Folding back the decision tree shows that the EV for the OP arm is 0.8×1 (probability of a negative surgical margin multiplied by the payoff value of a negative surgical margin) + 0.2×0 (probability of a positive surgical margin multiplied by the payoff value of a positive surgical margin) = 0.8. The EV for the RAP arm is 0.7×1 (probability of a negative surgical margin multiplied by the payoff value of a negative surgical margin) + 0.3×0 (probability of a positive surgical margin multiplied by the payoff value of a positive surgical margin) = 0.7. Hence, the EV for OP is higher.

The calculations involved in analyzing decision trees are simple arithmetic operations that can be performed manually or through spreadsheet programs. DA software is available (TreeAge, Williamstown and Syncopation Software, Concord, Massachusetts) and it can simplify the process. However, folding back models manually can facilitate understanding of the mechanics of DA and how one derives a seemingly arbitrary EV.

SENSITIVITY ANALYSIS

Sensitivity analysis is a crucial element of DA. It tests the stability of the conclusions of the base case analysis as well as the validity of model assumptions. Thus, an explicit statement of assumptions is important in model design. Frequently the probabilities of events and the values assigned to outcome states are uncertain or variable. In addition, studies may show conflicting findings with various values available for imputation into the model. During sensitivity analysis a specific parameter, eg probability at a chance node, is varied and the impact on the EV of treatment choices is determined. On 1-way sensitivity analysis a single parameter is varied across a realistic range, while all other values are kept constant. If the relative EV of the choices is unchanged, the analysis is insensitive to that variable. However, if the relative EV changes at a certain value of the parameter being tested, the point at which the optimal decision shifts from 1 alternative to another is referred to as the threshold value.

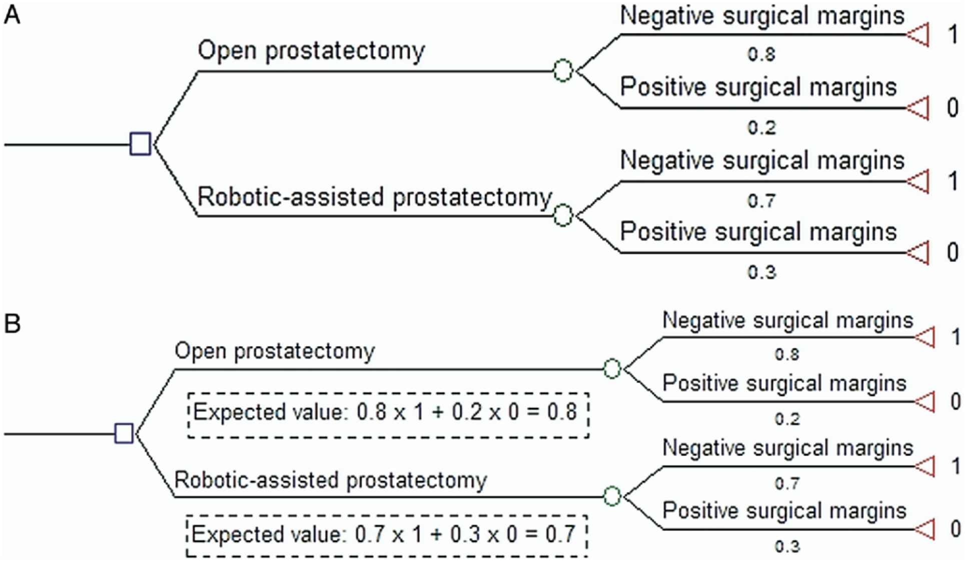

FIG. 1. Decision tree comparing open and robotic assisted laparoscopic prostatectomy. *A*, end point of interest is surgical margin status with utility values of 1.0 and 0 for negative and positive margins, respectively. Chance nodes (circles) represent possible outcomes with respect to margin status and listed fractions represent probability of each outcome state. *B*, folding back decision tree. Calculated EV for open prostatectomy is 0.8, representing weighted average of outcome states in that branch. Similarly calculated EV for robotic assisted prostatectomy is 0.7, representing lower result, reflecting greater chance of positive surgical margins.