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A diagnostic reasoning and optimal treatment model for bacterial infections with fuzzy information

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Summary This study proposes an optimization model for optimal treatment of bacterial infections. Using an influence diagram as the knowledge and decision model, we can conduct two kinds of reasoning simultaneously: diagnostic reasoning and treatment planning. The input information of the reasoning system are conditional probability distributions of the network model, the costs of the candidate antibiotic treatments, the expected effects of the treatments, and extra constraints regarding belief propagation. Since the prevalence of the pathogens and infections are determined by many site-by-site factors, which are not compliant with conventional approaches for approximate reasoning, we introduce fuzzy information. The output results of the reasoning model are the likelihood of a bacterial infection, the most likely pathogen(s), the suggestion of optimal treatment, the gain of life expectancy for the patient related to the optimal treatment, the probability of coverage associated with the antibiotic treatment, and the cost-effect analysis of the treatment prescribed.

1. Introduction

Two generic reasoning tasks are vital in medical reasoning: diagnostic reasoning and treatment planning. Diagnostic reasoning is the process of reconstructing the past facts from the observed evidence. Treatment planning is reasoning about the effects of actions treated on patients [1]. Usually, the practice of medicine requires both kinds of reasoning to work simultaneously. However, few current reasoning methods can conduct the two reasoning tasks successfully at one time. Besides, the reasoning systems become more complex when considering the complexity of human bodies and its relationships with the environmental factors.

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In some clinical cases, various factors may raise the difficulty in reasoning, such as the demographic variances of nosography, the incomplete knowledge of the diseases (e.g. severe acute respiratory syndrome (SARS) in the early 2003), some specific restrictions on estimating relevant parameters of the diseases, etc. In these cases, the clinicians' experiences and judgments may be useful to diagnosis and prescription. Therefore, the site-by-site factors and clinicians' knowledge, which may be expressed as extra constraints in the reasoning systems, need to be integrated into the medical decision support systems. At the same time, owing to the difficulties to estimate the causal effects between possible pathogens and the diseases, the parameters of the knowledge base can be expressed as fuzzy numbers.

Considering the clinical issues mentioned above, the authors are motivated to develop a reasoning model with the following features.

(i) Complete diagnostic reasoning as well as treatment planning.
(ii) Combine the formal knowledge base as well as decision-makers' judgments that present as extra constraints.
(iii) Work compatibly with the circumstance where fuzzy information is involved.

In the following section, the background of this research and the proposed approach will be interpreted.

2. Background

In medical informatics and other domains, Bayesian networks [1—10] and influence diagrams [6,8,11—13] are widely used knowledge representation and decision models under uncertainty. However, there are two limitations of utilizing the above approaches for solving medical reasoning problems:

(i) All associated probabilities are assumed to be crisp.
(ii) Difficult to consider the constraints for the relationships among the nodes in Bayesian networks or influence diagrams.
(iii) Treatment planning and diagnostic problems are not considered in one paradigm.

The limitations mentioned above restrict the practical usefulness of medical reasoning on Bayesian networks and influence diagrams in the following facts. First, the conditional probabilities between a node and its parent or children nodes could be fuzzy instead of a crisp numbers, due to the difficulties of learning accurately the cause—effect relationships among the nodes [14]. Second, as a common fact, the experts may have some professional speculations in the form of constraints when reasoning from a Bayesian network or an influence diagram. These constraints could be boundary, dependency, or disjunctive conditions. Third, the investigators of influence diagrams used to maximize the utility functions by node removal processes [11—13] and ignore diagnostic reasoning tasks. Oppositely, Bayesian networks have been used widely in probabilistic reasoning but lacked the capability to suggest the optimal decision [2,3,8—10].

This study proposes an optimization model to make diagnostic reasoning and treatment planning for bacterial infections, where the cause—effect relationships are expressed with an influence diagram and fuzzy data. The input information of the reasoning system are conditional probability distributions of the network model, the costs of the candidate antibiotic treatments, the expected effects of the treatments, and extra constraints regarding belief propagation. Since the prevalence of the pathogens and infections are determined by many site-by-site factors, the decisions involve uncertainty not compliant with conventional approaches. So, we allow the decisions to be made under fuzzy contexts, at which some of the parameters could be fuzzy parameters [14], and some constraints regarding diagnosis are introduced. When a patient is received, this reasoning system can, based on the present symptoms or bacteriological tests, help the clinician make precise diagnosis at the first decision point, and also supply the suggestions of optimal treatment for the infection. The outputs of the reasoning model are the likelihood of a bacterial infection, the most likely pathogen(s), the suggestion for the optimal treatment, the gain of life expectancy of the patient related to the optimal treatment, the probability of coverage associated with the antibiotic treatment, and the cost-effect analysis of the treatment prescribed. The input—output diagram is depicted in Fig. 1.

In the remaining of this article, the design considerations are introduced in Section 3. An influence diagram is used to represent the relationships among the variables relevant to the infections. In Section 4, this study describes the reasoning model and system thoroughly. In Section 5, we implement the diagnostic reasoning and planning problem as an optimization model. The illustration and solutions of this numerical example is given as well. In Section 6, some comments and lessons are given. Finally, we discuss the future extensions in Section 7.