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HEARTS: A Knowledge-Based System for Initial Screening of Heart Transplant Patients

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Abstract

HEARTS (Hospital Evaluation Assistant for Rapid Transplant Screening) is a knowledge based system (KBS) which conducts initial screening to determine if patients with coronary artery disease may be placed on the waiting list for a heart transplant. Given the critical shortage of donor organs, the medical community can only place patients who are likely to benefit from an organ transplant on the waiting list. Unfortunately, the process for screening patients is lengthy, approximately 4 months. During this time a donor organ may become available, but those patients still being screened cannot be considered as a possible match. We describe the development, testing, and user response to HEARTS. HEARTS benefits patients by speeding the screening process and placing them on the waiting list more quickly. Members of a transplant committee benefit by being freed from conducting the initial screening to focus on more critical issues.

Introduction

The shortage of organs for transplantation is widely acknowledged and the situation is not expected to improve. "Transplantation, with its extreme scarcity of resources, imposes some of the most critical and difficult choices in health care" (Penchas and Roll, 1996: 2347). In response to this shortage, information technology based initiatives such as XPEDITE (Beard, Klein, Daily, and Kauffman, 1997) to speed the matching of donor organs to a recipient have been undertaken. However, technology has not been as widely utilized to assist physicians with the task of screening candidates for transplantation. Specifically, not all patients are appropriate candidates for an organ transplant. Given the shortage of donor organs, it is important that only those patients who are most likely to benefit from a transplant be placed on the waiting list for transplantable organs. For example, if a patient suffers from a myriad of health problems such that they are unlikely to survive surgery or their general physical condition is likely to deteriorate even with a transplant, a patient will not be placed on a waiting list until their other health problems are treated or stabilized.

Heart transplant facilities have specific criteria that a patient must meet to be considered for a transplant. "Choices reflect priorities when determining transplantation procedure. If choices must be made, then one would tend to think that one would be better off if these priorities were established according to a pre-researched and established plan or system. After all, the choices (priorities) are repetitive. It would be wasteful to go through the same long and costly analytical process *da capo* each time" (Penchas and Roll, 1996, p. 2345). Currently, the decision to place a patient on a waiting list for a donor organ is a multi-step process that requires the input of a twelve person committee whose members include cardiologists, other physicians, registered nurses, social workers, and the chief of staff. However, the criteria for initial screening are complex, but set (known). Hence, a KBS could conduct initial screening. Since patients are excluded from receiving a transplant due to other medical conditions or lifestyle (i.e., smoking or alcoholism), the sooner a patient can receive feedback, the more quickly they can seek treatment to become eligible for a transplant. The committee benefits from the KBS as it frees them to focus on more critical issues such as the later stages of the screening process (which are more subjective), preparing patients for and performing surgery. The hospital benefits by knowing that initial screening criteria are applied in consistently.

Knowledge Acquisition

The criteria for screening a patient for transplant surgery are hospital specific. Different hospitals may accept patients with different risk factors depending upon the capabilities and experience of the transplant team. Therefore, HEARTS could not be developed from generic criteria, but must be specific to a particular hospital. Despite well-known medically-oriented KBS such as MYCIN, KBS are not commonly utilized in hospitals. Therefore, it was necessary to obtain special permission from the hospital's Heart Transplant Committee and Chief of Staff prior to meeting with two experts (also members of the Heart

Transplant Committee). That it took over three weeks to obtain permission is further evidence of the committee's workload and that a KBS that could streamline the screening process would be beneficial.

Knowledge acquisition was conducted by two of the authors (who served as knowledge engineers) with two transplant coordinators (registered nurses and members of the heart transplant committee). One of the knowledge engineers had completed 3 years of nursing school and had 3 years experience working in an emergency room as a nurse technician specialist. Her medical knowledge was essential when working with the experts. During the knowledge acquisition session, it became apparent that different screening criteria are applied depending upon the specific diagnosis. It was decided to focus on a single diagnosis and the experts requested Coronary Artery Disease. Knowledge acquisition was conducting via think-aloud verbal protocols with both knowledge engineers and experts present.

During the knowledge acquisition session, the experts manually evaluated a simulated test case. They developed a hierarchical diagram of their thought process as they made individual decisions about the case. The experts verbalized their thoughts as they proceeded. The knowledge engineers noted any inconsistencies that occurred. In addition, the other expert helped validate the process. Frequently the experts concurred. At other times they disagreed and discussed the acceptable manner to determine the correct path. These discussions reinforced our beliefs that a KBS that consistently applied the criteria would be beneficial. At the end of the session the one expert commented that "you don't realize how many things go into this in doing it until you write it down." Indicating they found some benefit from the knowledge acquisition process. During the session the experts generated two cases that were used later for testing.

Development and Testing

Diagnostic reasoning and medical diagnosis in particular are well-known domains for KBS. Further, rule-based knowledge representation schemes have been successfully applied to this type of reasoning. Since HEARTS is essentially a prototype to demonstrate the capability of KBS to the Heart Transplant Committee, a shell was deemed the best development approach. VP-Expert, a well known and readily available shell, was selected.

The rule-base was developed from the hierarchical diagram created by the experts during knowledge acquisition. HEARTS queries the user for information regarding a patients' medical condition. Based on the hierarchical diagram, the rules were broken into 3 major clusters. The first cluster examines basic information such as the patient's age, if they were properly referred, do they smoke, take non-prescription drugs, etc. When patients are excluded from the transplant program for these types of reasons, HEARTS recommends the appropriate next step for the patient such as seeking treatment for drug/alcohol abuse or quitting smoking and reapplying after a given time period, or contacting a more appropriate heart transplant program as shown in the rule below:

```
IF   Age = Yes                   ! Age > 65
THEN  Medical_Criteria = Not_ok
DISPLAY "Our hospital Heart Transplant program requires the patient's age to be less than 65. The
patient  may consider contacting Stanford's Heart Transplant Program.";
```

Note that all rules include a BECAUSE clause, which allows VP-Expert to respond to WHY queries, but were eliminated from these example for space reasons. The second rule cluster queries about additional health problems that might make the patient ineligible for a transplant at this hospital. Conditions such as peptic ulcers, vascular disease, active infections, or irreversable hepatic, renal or pulmonary disease. Each condition is evaluated a separate rule, if none of these conditions are found, the rules that comprise the third cluster are evaluated. This cluster evaluates more complex conditions including the status of patients with diabetes, hypertension, cancer, etc. Below are three rules used to evaluate hypertension:

```
IF   Systolic >= 160             !Evaluate for hypertension
AND Diastolic < 100
THEN   Hypertension = Yes;


IF   Hypertension = Yes
And Medication = No              !Is the patient taking medication for hypertension?
THEN   Medical_Criteria_2 = Not_ok
DISPLAY "This patient needs to be evaluated for medical treatment for hypertension. This patient
can be re-evaluated after hypertension  is managed by medical therapy.";


IF   Hypertension = Yes
AND Medication = Yes             !Hypertension medication is not working
THEN   Medical_Criteria_2 = Not_ok
DISPLAY "This patient's medical therapy is not controlling the hypertension within acceptable
boundaries.  Re-evaluate when the patient's hypertension is under control with medical therapy.";
```

If, based on HEARTS' evaluation, a patient meets all criteria, further laboratory work is conducted and utilized by the committee to conduct the final stage of screening.

Two test cases developed by the experts and a third created by the knowledge engineers were used to determine if HEARTS was giving accurate recommendations. During testing, HEARTS sometimes failed and it was difficult to pin-point the step in the query causing the failure. The failed case was re-executed using the VP-Expert's auto-query function which enabled the system to request the information necessary to complete the case. By doing so, it became apparent that a *gap* (Gamble and Shaft, 1996) existed in the rule-base. Specifically, the initial and final portions of the necessary rule-chain were in place, but the rules in the initial portions of the rule-chain were not instantiating all the variables necessary to fire the appropriate rule in the final portion of the rule chain. Although the gap would have been detected and corrected manually, auto-query speeded the debugging process and subsequently was used to test all rule combinations.

User Feedback and Future Plans

Following testing, HEARTS was demonstrated to the experts by executing the test cases. The experts then used HEARTS to run other cases on their own. Their response was positive and they felt that HEARTS would save time when screening patients and they planned show HEARTS to the other members of the Heart Transplant committee and the Chief of Staff. Depending on their responses, the experts will propose development of full-scale version of HEARTS. In addition to being useful in the Heart Transplant department, the experts believe that other areas of the hospital could benefit from KBS and intend to introduce HEARTS to the Congestive Heart Failure clinic. In the future, a second phase of development may be conducted to expand HEARTS' rule-base to conduct later steps in the screening process. These additional steps consider laboratory test results and other medical procedures before recommending a patient be placed on the waiting list.

Conclusion

Amazing technological advances have been achieved in medicine, such as a robot that performs surgery (see http://www.musculographics.com/krs.com). However, when an entire medical procedure is examined it is apparent that technology is almost non-existent in initial diagnosis. HEARTS demonstrates the ability for KBS to conduct routine diagnostic activities which could enable the medical community to better allocate scarce resources.

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