QUALITATIVE REASONING AND DECISION TECHNOLOGIES
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A QUALITATIVE APPROACH TO DIAGNOSIS IN NUCLEAR MEDICINE

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ABSTRACT

Mathematical models of pathophysiological processes have been ocasionally used in computerized medical diagnostic systems. Nevertheless, the lack of biological knowledge was a constraint in developing diagnostic programs, which were usually related to topics such as farmacotherapy or acid-base equilibrium. The introduction of a new generation of expert systems, using "deep" knowledge instead of heuristics, promised new ways in implementing causal relations in medical expert systems. We have explored this new approach working on an expert system for diagnosis of SPECT images of myocardial perfusion.

1. INTRODUCTION.

Myocardial infarction is commonly assessed by means of clinical findings and cardiovascular nuclear medicine images. Over the last years, we have been working in collaboration with the Medical Informatics Lab at the Georgia Institute of Technology, in a diagnostic system for myocardial infarction. This project, PERFEX, aims to build a rule-based expert system for interpreting 3D myocardial perfusion distributions, obtained from Thallium-201 single-photon emission computed tomography (SPECT) images, which is now being replaced by Sestamibi Tc-99m-04.[1]. PERFEX incorporates clinical information such as sex, age, chest pain symptoms, and EKG s-t segment depression for evaluating coronary artery disease from stress and delayed (redistribution or "at rest") perfusion studies.

The expert system reports a patient condition which provides a likelihood associated with the location and shape of each myocardial perfusion defect, as well as suggestions regarding a possible coronary lesion. Verification studies confirm that the results are similar to experts' interpretations [2]. PERFEX is now undergoing further evaluation in a different clinical setting.

Nevertheless, other issues require further assessment; i.e., the explanation module will require improvement, like other questions such as robustness and user-friendly interface. Furthermore, it would be clinically interesting to incorporate some predictive or prognostic assessment capabilities, which seems now possible using myocardial thickening information.

In this regard, causal reasoning methods could improve the diagnostic characteristic of the system, incorporating pathophysiological knowledge at different levels. The incorporation of myocardial thickening during systole, with a clear prognostic value, could enhance the explanation capabilities of PERFEX. The problem of explanation in medical expert systems has been a severe one, since physicians usually do not accept the use of "black-boxes" in computer-assisted diagnosis.

2. BACKGROUND AND RATIONALE.

2.1. Myocardial thickening: a pathophysiological mechanism for prognosis?

Research groups have reported that, in laboratory experiments made with dogs, there is a correlation between myocardial thickening and myocardial perfusion [3][4]. Left ventricular myocardium reflects an end-diastolic thickness of approximately 1 cm and thickening during systole of approximately 50%. With myocardial infarction, there are motion abnormalities and myocardial thickening during systole is reduced.

Sestamibi Tc-99-m have proved to be an excellent means to assess myocardial perfusion. Researchers at Emory University School of Medicine have also reported that, in humans, the assessment of wall thickening during systole, using Sestamibi Tc-99-m04, could provide additional information of tissue viability, and myocardial perfusion.

A high correlation of thickening with resting perfusion has been shown. This finding represents a possible marker of myocardial functioning, since the predictive value of absent systolic wall thickening (SWT) for fixed segments has been reported to be near 100%. Thus, the presence or absence of SWT appears to be a reliable indicator of myocardial viability.[5]

2.2. Causal reasoning in medicine.

The first medical expert systems (i.e., MYCIN, INTERNIST) were based on the heuristic knowledge of experts, using rules of thumb to reduce the space of search in a knowledge base. Certainty factors were used to weight the relations between findings and hypothesis, a scaled conditional probability of the diagnosis given the confidence of the conclusion [6][7][8].

These pioneer systems were only ocasionally used in clinical settings, due to different questions. Among these problems, the lack of complete explanation capabilities and the need for a detailed anatomic and physiological information in the rules included in the knowledge base have been justified.

The introduction of new techniques, incorporing the concept of "deep" knowledge, to make use of causal structure of diagnosis to couple with hypotheses generation can overcome the incompleteness of the heuristic expert systems, to take better account of interaction among diseases. The concept of "deep" knowledge, related to the association between causes and effects in medicine, mainly in aspects related to physiology or pathophysiology, includes two general types of description:

- QUALITATIVE (causal): a system is described in terms of the behavior of each component and its effects on the rest of the system..

- QUANTITATIVE: a description in terms of mathematical expressions.

A cognitive justification has been used to support causal reasoning. I.e., research groups [9] have reported that studies made to account for clinical reasoning processes in physicians, using protocol analysis, have showed the use of physiological knowledge in terms of qualitative expressions of continous variables and the constraints among them. Other research centered on qualitative reasoning about physical systems [10] can also be cited for their interest in medicine.

Several systems have incorporated this kind of causal knowledge in medicine, such as the following:

(1) CASNET. It used a semantic network for the diagnosis and treatment of glaucoma, with multiple levels of detail. It also incorpored a function for calculating likelihood in all pathways [11].

(2) ABEL. Patil and coworkers at MIT constructed a successful model to represent causal explanations in the context of acid-base and electrolyte disorders. ABEL uses three levels of description, from a high level to a low and specified one. Some characteristics are represented in all levels [12].

(3) QSIM [6]. Kuipers has studied the problem of qualitative model-based reasoning, for its possible predictive value. He observed that weighting associations between findings and hypotheses, made it impossible for traditional expert systems to express causal mechanisms. Also, he and his colleagues analyzed verbatim transcripts of expert physicians solving selected clinical problems, and this resulted in a knowledge representation and a qualitative simulation algorithm (QSIM). Within this representation, he built a structural description for the mechanism studied in the transcripts, and the simulation seemed to produce the same qualitative prediction made by the physicians. The key concept is the use of landmark values for variables (values at which the qualitative functions change behavior). The explanation of the knowledge representation refers only to a small set of objects and relations.

(4) CHF Advisor [13]. This program aimed to serve as a consultation aid in cases of congestive heart failure. Various different diseases can produce similar features, and therefore a causal reasoning approach can enhance the differential diagnosis capabilities. CHF uses a truth-maintenance system to propagate the effects of changes in a parameter value to the rest of the model, because of the causal relations among states, and then observe how that model reacts. A belief network was also introduced to assess probabilities.

A different approach to CHF, using case-based reasoning techniques, has been implemented in its sucesor CASEY [14].

(5) KARDIO [15]. Kardio is a qualitative model that simulates the electrical activity of the heart, and is used in an expert system for diagnosing cardiac arrhytmias. The system incorporates a qualitative model which simulates the electrical activity of the heart. Bratko and coworkers designed a set of Prolog clauses, and using inductive machine learning techniques (ID3), rules were obtained to construct a knowledge base.

These programs are among the best known models of qualitative reasoning in medicine at present. It is also interesting to point out that most of them deal with cardiac features. Nevertheless, there are no real paradigms or widely accepted methodologies for the use of causal methods in medicine. Other approaches are also interesting, such as the Widman's cardiovascular modeling, with a system that maps the values of qualitative variables into semiquantitative terms, by giving values to terms such as "normal", "elevated", "high", etc., that are mapped into the internal system (-1......0........1), with 0 being "normal" [16]; XPLAIN [17] generates explanations at multiple levels, and NESTOR [18] uses a causal tree associated with probability coefficients.

3. Causal reasoning in PERFEX.

Studies in medical diagnosis have proved that experts use a wide range of techniques, varying among domains. Pathophysiological knowledge is used by both novices and specialists, although the latter have better mechanisms to combine different information (patterns, literature, patients seen previously, etc.). We have studied the mechanisms underlying the development of myocardial infarction, which are commonly accepted —at least in a low detail level—. We can summarize the phases in myocardial infarction according to this general classification.The highest level would be myocardial infarction and the lowest level would be biochemical interactions, as follows:

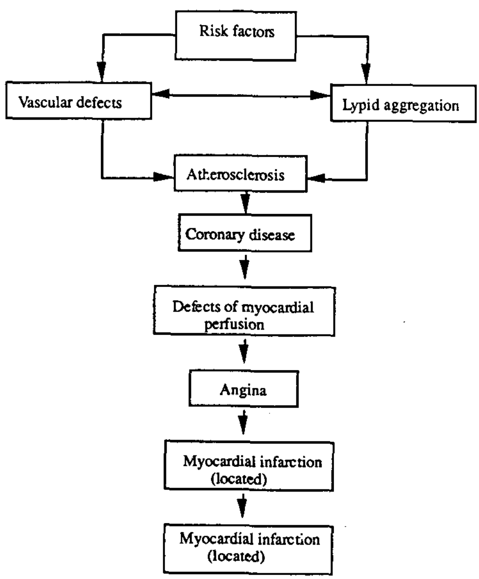

Fig 1. Schema of stages in the development of myocardial infarction.

We considered the advantages and disadvantages of this approach, as follows:

- Advantages: (1) Qualitative reasoning are currently available to represent causal mechanisms in a cardiac expert system; (2) A number of research reports have shown the wide range of possibilities available to the researcher; (3) The use of heuristics in a cardiac expert system is only an incomplete method to represent medical knowledge in expert systems, showing the need for other methods.

- Disadvantages: (1) The amount of information and knowledge required to model the behavior of the system, if we consider all the possible causal relationships between states (2) Previous similar reports have considered reduced medical domains (3) There are no commonly accepted paradigms or methodologies. It is also difficult to accept that the concept of "deep" knowledge is only related to qualitative or causal knowledge, and even more, that classical expert systems did not incorporate this type of knowledge.

- Incomplete knowledge of cardiac pathophysiology. It is very difficult to model all the knowledge needed (for instance, the developers of QMR considered that 100 person-years would be necessary to build a "deep" QMR, not worthwhile for established researchers).

In our study, there is a clear advantage over other previous research approaches. Myocardial thickening during systole has proved to be a important predictive factor in myocardial viability, and a complete pathophysiological model is under development in a clinical research setting. The results of this work aim to eliminate costs and patient risks, since the analysis of Sestamibi Tc-99m-04 imagery and laboratory studies can reduce the number and intensity of tests needed to diagnose accurately a cardiac patient.

A qualitative approach has been considered to infer predictions of the behavior of the system, in a similar way to the one successfully used in engines and electrical circuits [10]. The collaboration between clinical researchers and computer developers can enhance robustness and consistency, as well as serve as a model for future development in systems designed to model behavior in causal expert systems. A number of questions in methodology and clinical usefulness remains still unclear.

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