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DECISION MAKING PROCESS IN CARDIAC SURGERY – CONCEPT OF BUILDING AN EXPERT SYSTEM

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Abstract:
The fundamental goal of modern information technology is to support decision making process in organizations, for both routine and highly complex problems, based on heterogeneous data sources. The main objective of the paper is to present the construction concept of knowledge base for an expert system designed to support the decision making in cardiac surgery. A knowledge-based medical expert system is designed to support decision-making process in cardiac surgery where knowledge from medical guidelines, risk scales, and registries is applied to reason the medical procedure in a particular case scenario.

Key words: *expert system, cardiac surgery, knowledge base, decision-making process*

INTRODUCTION

The extent of contemporary medical knowledge results from an ongoing development as well as scientific and technical progress in healthcare. Medicine is still regarded as an art of science, however this point of view has significantly developed over the past ages. Uniform therapeutic indications and treatment approach have introduced standardized medical care. Continuous healthcare policing has improved treatment outcomes and overall patient safety, decreased the incidence of malpractice, and introduced cost-effectiveness and economic approach into healthcare. Progress and improvement of medical care requires observation of guidelines and medical standards by healthcare professionals. It is still expected though, that clinicians will maintain their practices in accordance with novel techniques, improved methods, and treatment approach. Medical professionals are supported in their clinical daily routine by increased delivery of scientific papers, new versions of guidelines and recommendations, and updated risk scales. Although information received is complimentary, uniform presentation requires complex data processing and integration of information from various sources and areas of medicine.

Decisions made in clinical medicine result in a series of events in the whole environment of medical center. Selected medical therapy requires use of particular medical equipment and device. In some cases, as a consequence, this may cause temporary alterations of center‘s activity, including hiring additional staff, extra costs and spending. The primary goal of this approach is patient survival and optimal recovery, and in case of active employees – return to normal work. Unfavorable medical decisions are usually undertaken because of lack of extensive and current medical knowledge, mistaken analysis of various factors or due to ignorance of medical checklist. It is conceivable that properly designed search engine would mine through available registries and present comparable case study for assessment whereas not every clinical scenario could have been previously described in medical guidelines. Each patient undergoing medical procedure is at risk of temporary or long-term disability or even death. Every medical complication generates an organizational hurdle for the medical facility and is associated with increased costs of treatment. Medical treatment costs that exceed standard therapy (based on diagnosis related groups – DRG) directly influence the hospital economic balance. Patient rights are well-defined in legal acts and give way to compensation demands against the staff and medical center.

This complex decision-making process could have been supported by applied systems of artificial intelligence based on available sources of knowledge. The system would replace neither human decisions nor responsibility, but it would help to identify the best procedure, especially in the most complicated cases. In this paper we present one of the most technologically advanced medical specialty, cardiac surgery, with brief description of the sources of knowledge available and the characteristics of knowledge engineering and methods applied to generate an expert system.

Cardiac surgery – overview of the knowledge sources

Cardiac surgery is an invasive (surgical) medical specialty designed for treatment of heart diseases. Despite clear anatomical borders for cardiac interventions, surgeons must be proficient in other medical specialties, such as: thoracic and vascular surgery, cardiology, intensive care, transplantation, etc. Cardiac surgery influences wide areas of socio-economic life of the society: circulatory disease is a leading mortality cause in Poland. Medical costs associated with cardiac interventions are of the highest among medical specialties. Decision-making in cardiac surgery is a complex process that involves a whole team of specialists: cardiologists, cardiac surgeons, anesthesiologists and others. Various criteria are taken into account in this process including individual professional experience, opinion of other experts in the field, and most importantly the unbiased sources designed to support decision-making in specific medical cases: medical guidelines, standards, and risk scales.

Guidelines are elementary tools used by cardiac surgeons in medical assessment. They are issued based on limited sources of information, which are mainly historical (previously published) and therefore do not present up-to-date state-of-the-art in cardiac surgery. The sources of information in cardiac surgery include: results of randomized, prospective, multicenter clinical trials and other, including meta-analyses, as well as expert opinions invited to participate in work groups to establish the rules of conduct in specific types of clinical scenarios. The above-mentioned lay ground for medical guidelines (recommendations) for particular clinical diagnoses, are limited to most common cases and do not cover every possible diagnostic and therapeutic scenario. Another limitation of the guidelines is extrapolation of uniform therapeutic assumptions for entire patient population whereas source data have been obtained from selected groups of patients in individual clinical studies. Guidelines in cardiac surgery are published by a whole range of multidisciplinary scientific societies: European Society for Cardiovascular Surgery, European Association for Cardio -thoracic Surgery, Society of Vascular Surgery, American Heart Association, European Society of Cardiology, and others.

Medical standards warrant uniform procedures and increase safety at every stage of medical approach. Of note, although very helpful, current standards of care do not refer to the most complicated medical cases. Standards of care rather define the scope of possible treatment strategies for specific scenarios in medicine. Although the overall goal is to apply medical standards to avoid common errors in the therapeutic process, these are typically limited to specific country, region or even medical facility, and cannot be universally utilized in every cardiac surgery center.

Healthcare professionals also exploit medical registries that combine well-organized clinical facts and data including cases where medical treatment was conducted in accordance with the guidelines as well as scenarios not described by recommendations where therapy was selected based on clinical experience of the medical team. In addition, each center may develop local registries and allow medical judgment based on expert consensus provided the presented case is beyond medical guidelines. The three most characteristic limitations of each database are accuracy, expense, and analysis. For each database full-time dedicated staff, adequate resources, and a system to ensure data integrity are essential. Of these, dedicated and committed staff is the most important and expensive. The value of people responsible for data collection and input cannot be overemphasized: they require educational support by the surgeons to ensure that clinical information is accurately and consistently interpreted for data entry. The value of a database is dependent on valid data [14].

Risk scales are helpful in uniform groups of patients, particularly to justify treatment strategy in extremely risky procedures. Risk scales have been designed to predict early mortality and morbidity of the reference class of patient population, and refer to large databases originating from volunteering units, without external validation of the dataset in many cases. Most common risk scales in cardiac surgery are EuroSCORE and STS. Even moderate levels of error can lead to substantial inaccuracy in estimates of mortality rates and in some circumstances these inaccuracies can be gross, especially at the low mortality rates that are now prevalent in cardiothoracic surgery [4].

High cost, complexity and competition among cardiac centers also bring the need for a computer support that will provide unbiased information on best optimal treatment for the particular case, surgical strategy and planning – including optimal bed assignment, local risk stratification and cost associated with complications, cost-effectiveness and procedure cost evaluation. Integration of all available medical knowledge into an expert computer application will help assess the risk of malpractice or human error during patient evaluation for surgical treatment.

Characteristics of the knowledge engineering

Knowledge engineering is an experimental science. Many methods for knowledge representation have been developed; knowledge bases were created in various areas. It is observed, however, that the source of progress in knowledge engineering are experiments and research on representation of specialized practical knowledge, verified in particular applications, such as medicine. Specificity of problems knowledge engineering is facing might be contained in the simplified statement that the knowledge from each field can be potentially formalized, but a significant bottleneck of such activity is the complexity of the given field, the degree of knowledge openness and the structure of knowledge sources. The more complex and dependent on scattered sources the field is, the higher challenge it makes for knowledge engineers. Simplified models, making a certain fragment of the given whole, seem to work normally, whereas working out the foundations of a complex system gives rise to a number of difficulties. Knowledge engineering proposes methods that can support this laborious process, but it does not present ready solutions for the particular area – since these must be created through cooperation among knowledge engineers and experts in the given discipline.

At first knowledge engineering comprised mostly tasks connected with knowledge acquisition for expert systems. Today it can be presented as a field connected with creating knowledge bases and using semantic technologies for knowledge processing by computer systems [5]. The issues falling within the scope of knowledge engineering comprise methods for knowledge acquisition (including acquiring knowledge from experts, knowledge discovery in databases, text documents), ways of knowledge representation, knowledge formalization, methods for knowledge analysis, knowledge processing [13].

Current state of development in knowledge engineering for cardiac surgery worldwide can still be defined as pioneering. Studies on related disciplines have been published for cardiology [3, 6, 12, 16], infectious diseases [1, 7], and oncology [2, 10]. Knowledge used by cardiac surgeons mostly occurs in the form of a text document and databases (registries). Only few operative risk scales are available as interactive Internet forms and applications accessible to the users of mobile devices. There have not been published any interactive forms of knowledge base for treatment guidelines for e.g. ischemic heart disease.

It is conceivable that expert systems computing medical standards, guidelines as well as risk scales and procedure costs would support medical professionals in optimal treatment selection and planning.

MATERIALS AND METHODS

Prior to design of knowledge base to support decision making process in cardiac surgery a formal model and research methodology has to be developed. This is achieved by solving the following steps:

- Location and organization of knowledge sources in cardiac surgery,
- Working out methods for acquiring and gathering knowledge on the basis of located knowledge sources and experiences of experts in cardiac surgery,
- Working out a formal model for field knowledge in cardiac surgery using a rule-based formalism.

Development of expert system requires studies on the possibility of knowledge arrangement and formalization in such highly complex domain like cardiac surgery. A unique research team consisting of specialists in cardiac surgery (medical experts) and knowledge engineering will design a research model including the process of field knowledge acquisition and update of guidelines and recommendations. Later, the hypotheses on feasibility of field knowledge formalization in cardiac surgery for the future application in decision-making process will be verified. At current state of knowledge it is feasible to develop a formal model of field knowledge in cardiac surgery based upon medical guidelines and standards. The formal model would develop knowledge base to perform meta-analysis of medical recommendations and assess risk associated with selected medical procedures. It also seems possible to develop a formal model of field knowledge in cardiac surgery for specific geographic region with application of medical registry data mining. The formal model of specific knowledge would compare guidelines and recommendations with actual clinical daily practice in the requested area. The more specific, i.e. limited to the country, region or medical center is the registry database, the more accurate information can be provided on what sort of treatment strategy is being offered to the patient that seeks medical care. Development of a formal model of economic knowledge that would include procedure costs and estimated length of hospital stay and support decision-making process from the perspective of cost-effectiveness in cardiac surgery would be possible.

Within the framework of the initial research described in a publication by the authors of the project [11] literature analysis was made in order to assess the state of knowledge in the studied area, which allowed to show the usefulness and originality of the problem chosen for research. Also an analysis of some sources of knowledge was performed (including the guidelines of the European Society of Cardiology) to acquire and formalize knowledge on surgical treatment of aortic valve disease. The final set of rules comprised a small subarea of problems, which ultimately need to be analyzed. However, this simple model has already distinguished early problems (concerning the acquisition, structuralization of knowledge), significant from the point of view of formalizing knowledge in cardiac surgery. Therefore many different experimental models have to be developed to build a consistent formal model.

Scientific technique and research process can be described through the planned work stages:

- Analysis and reviews of literature understood as deepening of analysis in respect of the state of science in the studied area. As part of preliminary research, the analyses have already been made which have allowed the usefulness and originality of the problem intended to research,
- Adaptation of the results of other authors' studies – thorough analysis of other scientific works is also supposed to allow the evaluation of possibilities for adaptation of some solutions, for instance in the constructed knowledge model the authors consider using the medical terms described by the current ontologies, e.g. the medical terms classification SNOMED,
- Location and organization of sources of knowledge in cardiac surgery – the work on the analysis of knowledge sources will be carried out throughout the process of working on the project, while in the initial phase a detailed analysis will be made concerning the structure of knowledge contained in the available sources. An important problem is the precision of knowledge sources in the form of guidelines. Guidelines not always show clearly enough which component conditions (determining the way of conduct) are of priority importance in relation to the other. It may turn out that in an untypical situation, the recommendations of guidelines are difficult to use. In such cases it may be necessary to locate and use other sources of knowledge,
- Adaptation of the results of other authors' studies will also include methodologies describing the process of knowledge acquisition, gathering and formalization. As a result of critical analysis of the results of research within this scope, conducting experiments for chosen approaches and based on this, developing the authors' own adaptation of the methodology in this area is planned,
- The above mentioned works will allow making a formal model for field knowledge in cardiac surgery using rule-based formalism. It was assumed that a particular disease entity will be the developmental unit of the model. For each disease entity, the correctness of rules will be checked (in respect of coherence, contradiction, coinciding of rules), as well as their completeness. After this stage, the knowledge model will be verified concerning the facts by experts – doctors being members of the research team – if it includes all the schemes of surgical treatment required at the given unit.

In the course of knowledge formalization for cardiac surgery, it is of great importance that there is a possibility of developing expert system prototypes for the next fragments of a knowledge base coded on the basis of the developed formal model. Prototypes will be worked out using the field-independent tool used to build expert systems, PC-Shell from the artificial intelligence package Aitech Sphinx, which was already used in medicine, for instance in psychiatry for diagnosis of affective disorders, and the work in this field is continued [9]. PC-Shell is a system of hybrid architecture, i.e. combining different methods for problem solving and knowledge representation. One of interesting properties of the PC-Shell system is a built-in, fully integrated, simulator of a neural network. Another essential character of the PC-Shell system is its blackboard architecture, allowing the division of a large knowledge base into smaller modules, orientated thematically – which will be particularly useful in the designed system, on account of substantial scattering of knowledge sources.

The methods of the study used within the framework of the one of research hypothesis – possibility for expanding the knowledge base with knowledge from medical registers documenting actual medical events – will be subordinated to rules of conduct in the course of performing tasks on data exploration, such as a reduction of feature space dimension, classification, data clustering or association discovery. After a detailed identification the character of data that is supposed to be added to the knowledge base – a selection of data mining algorithms will be made, including artificial immune systems [8], confirmatory Factor Analysis [15]. The decision about choosing an algorithm will be taken based on measures calculated in the course of verification and used methods for results visualization.

To verify the medical registers (making statistical analysis – initial stage of data exploration), the authors intend to use tools provided by the WEKA library (Waikato Environment for Knowledge Analysis) worked out by the University of Waikato in New Zealand as an open source software under GNU General Public License, which makes a useful tool for a circle of scholars dealing with machine learning, data analysis and data mining. Moreover, using such tools as the R program is anticipated. R is a programming language and development environment, which allows making statistical calculations and data visualization. The source code R is also published under GNU GPL license, and the program itself provides a wide range of statistical techniques, at the same time allowing independent modification of the used algorithms, which at such a novel project will be a significant asset.

RESULTS

The initial expert system prototype has begun proper function after insertion of the rules from the European Society of Cardiology guidelines for valvular heart disease (aortic valve surgery). For the need of PC-Shell expert system, isolated sections have been separated: lexical (facets) and the rules of procedure (rules). Facets describe attributes, possible values, and optional question wording. The course of consultations with the user is characterized by the level of details of questions, which depends on the wording of the rules. For example, in the case of query about the range of systolic left ventricular dysfunction rule checks the value of left ventricular ejection fraction, which means that the system asks for the exact numerical value (Fig. 1).

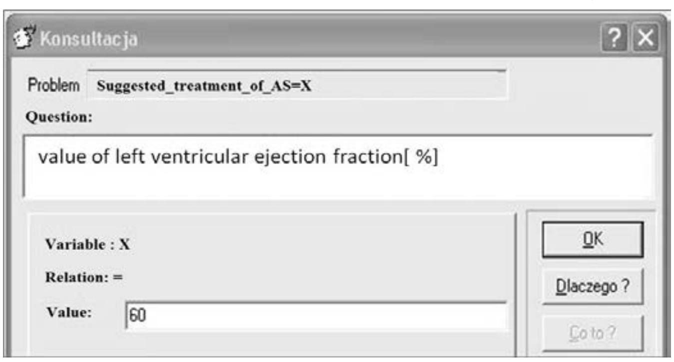

Fig. 1 The question about the value of left ventricular ejection fraction

Whereas in the assessment of the degree of the valve calcification and increased peak flow the rule checks only whether it occurs: the system asks the user if this situation happens at all but not wishes to ascertain about the exact value of the flow rate (Fig. 2).

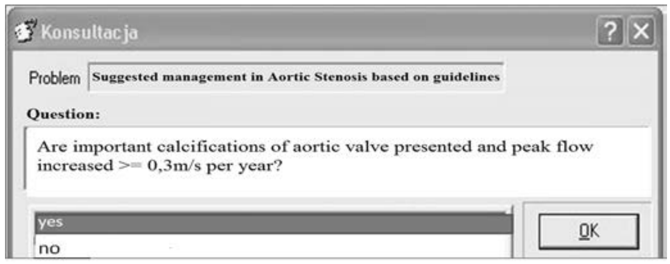

Fig. 2 The question about the presence of aortic calcification

The result of a sample consultation shows Fig. 3. Prototype system has confirmed indications for surgery and presented a scheme of inference.

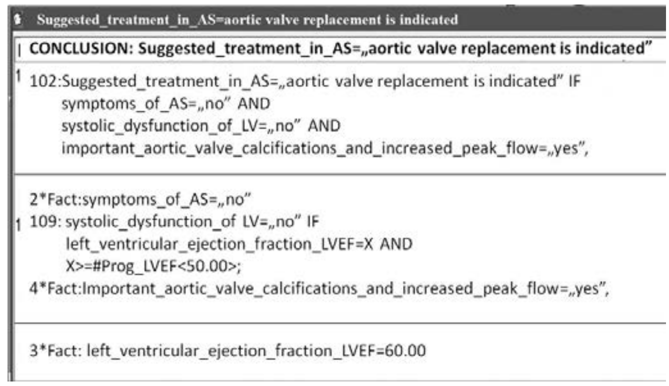

Fig. 3 The result of an example consultation

CONCLUSION

Successful performance of the project requires transparent and continuous exchange of expectations, thoughts, and needs between two independent study participants: computer scientists skilled in knowledge engineering and medical professionals (cardiac surgeons) who feed the system with their proficiency in medical guidelines, standards, rules of conduct, and clinical routine. There is no research model available to adapt for the proposed project: no medical guidelines have been translated into logic-based rules, medical registries are not assembled as knowledge base, nor have economic results of medical centers been associated with risk modeling. Extensive and specialist field knowledge in cardiac surgery is going to be translated into knowledge base for the first time in this project. Design of the formal model that will address the above-described problem requires creation of unique methodology where characteristics of scientific domains involved will be reflected both in terms of knowledge engineering as well as complexity of the domain. The research methodology will accommodate study results on verification of knowledge engineering methods applied for the first time in cardiac surgery. Adequacy of applied research methods will be verified and unique methodology is going to be developed in this project.

Provided the well-defined sources of information, the system knowledge is going to be sufficient to perform deep and unbiased deduction. Thorough and updated knowledge installed in this universal system will enable a real life case conference, where recommended mode of treatment along with associated risks and medical costs are going to be presented for the inquired medical case. Independent structure elements will provide various data source installation. This will create unique expert tool available and applicable to individual requirements (medical providers, patients, insurers, students, etc.) worldwide.

REFERENCES

[1] Adlassnig K.P., Blacky A., Koller W.: Artificial-intelligence-based hospital-acquired infection control. Stud Health Technol Inform. Vol. 149, 2009, pp. 103-110.
[2] Avci E.: A New Expert System for Diagnosis of Lung Cancer: GDALS_SVM. J Med Syst. Vol. 36, 2012, pp. 2005-2009.
[3] Dassen W. R., Karthaus V. L., Talmon J. L., Mulleneers R. G., Smeets J. L., Wellens H. J.: Evaluation of new self-learning techniques for the generation of criteria for differentiation of wide-QRS tachycardia in supraventricular tachycardia and ventricular tachycardia. Clin Cardiol. Vol. 18, 1995, pp. 103-108.
[4] Gallivan S., Stark J., Pagel C., Williams G., Williams W.: Dead reckoning: can we trust estimates of mortality rates in clinical databases? European Journal of Cardio-thoracic Surgery. Vol. 33, 2008, pp. 334-340 .
[5] Gołuchowski J. (red.): Wprowadzenie do inżynierii wiedzy. Difin, Warszawa 2011.
[6] Heden B., Edenbrandt L., Haisty Jr. W. K, Pahlm O.: Artificial neural networks for the electrocardiographic diagnosis of healed myocardial infarction. Am J Cardiol. Vol. 74, 1994, pp. 5-8.
[7] Kopecky D, Adlassnig K. P, Prusa A. R, Hayde M, Hayashi Y, Panzenböck B, Rappelsberger A., Pollak A.: Knowledge-based generation of diagnostic hypotheses and therapy recommendations for toxoplasma infections in pregnancy. Med Inform Internet Med. Vol. 32 (3), 2007, pp. 199-214.
[8] Kempa A.: Specyfika sztucznych systemów immunologicznych. Studia i materiały Polskiego Stowarzyszenia Zarządzania Wiedzą, Polskie Stowarzyszenie Zarządzania Wiedzą. Nr 37, 2011.
[9] Kwiatkowska M., Michalik K., Kielan K.: Computational Representation of Medical Concepts: A Semiotic and Fuzzy Logic Approach, [in:] Soft Computing in Humanities and Social Sciences. Springer-Verlag. Heildelberg 2012.
[10] Makal J., Nazarkiewicz A., Oniśko A., Orzechowski P.: System ekspertowy do wspomagania diagnozy łagodnego przerostu prostaty. Pomiary Automatyka Robotyka. Nr 7-8, 2004.
[11] Maruszewski M., Kempa A., Michalik K., Zacny B., Hrapkowicz T.: Koncepcja bazy wiedzy systemu ekspertowego dla kardiochirurgii [w:] Sobczak A. (red.): Technologie informatyczne w administracji publicznej i służbie zdrowia. Zarządzanie cyfrową transformacją organizacji publicznych, Roczniki Kolegium Analiz Ekonomicznych, 2012.
[12] Rabelo Júnior A., Rocha A. R., Oliveira K., Souza A., Ximenes A., Andrade C., Onnis D., Olivaes I., Lobo N., Ferreira N., Werneck V.: An expert system for diagnosis of acute myocardial infarction with ECG analysis. Artif Intell Med. Vol. 10(1), 1997, pp. 75-92.
[13] Sołdek J., Pechmann P.: Wiedza – istota, pozyskiwanie i wykorzystanie w przedsiębiorstwie, w: Sołdek J. (red): Metody Informatyki Stosowanej. Kwartalnik Komisji Informatyki Polskiej Akademii Nauk Oddział w Gdańsku. Tom 11, nr 1, 2007, s. 23-38.
[14] Williams W. G.: Uses and Limitations of Registry and Academic Databases. Seminars in Thoracic and Cardiovascular Surgery: Pediatric Cardiac Surgery Annual. Vol. 13, Issue 1, 2010, pp. 66-70.
[15] Zacny B.: Konfirmacyjna analiza czynnikowa w badaniach ekonomicznych, [w:] Zeliaś A. (red.): XX Seminarium Ekonometryczne im. Profesora Zbigniewa Pawłowskiego. Materiały z XXXVIII Konferencji Statystyków, Ekonometryków i Matematyków Akademii Ekonomicznych Polski Południowej. AE w Krakowie, Kraków 2004, s. 359-369.
[16] Yang T. F., Devine B., Macfarlane P. W.: Artificial neural networks for the diagnosis of atrial fibrillation. Med Biol Eng Comput. Vol. 32, 1994, pp. 615-619.

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