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Research and Education

Medical Informatics Research and Education at the Erasmus University in Rotterdam

Introduction

The Department of Medical Informatics at the Erasmus University was established in 1987, as part of the Faculty of Medicine and Health Sciences. At present, the department involves about30 people, some of whom have a joint appointment with another department or work part-time. The scientific staff consists of 12 people (7 faculty); there are currently 12 PhD students.

Medical informatics is a young discipline, and like many evolving disciplines has struggled to define and demarcate its own field of research from that of other related disciplines. We define medical informatics as the science that studies methods and techniques to formalize medical decision making and treatment, aiming to support these activities with the use of computers. An essential aspect of these methods and techniques is that they should be applicable to different problems. Specific application areas, however, not only need general tools but also specific expertise. Thus, medical informaticians often work in close collaboration with domain experts. As we will see, this is also true for most of the projects carried out at our department.

The first part of this overview will describe the main lines of research of the Medical Informatics Department at the Erasmus University. In the second part, the educational activities of the department will be presented.

Research

Research at the Department of Medical Informatics in Rotterdam is concentrated in two main lines of research: *structuring medical data* focusses on the computer-based patient record (CPR) and related topics, while *structuring medical knowledge* hasdecision-support systems as one of its main application areas. When these systems support the interpretation of biosignals or medical images, they may require the automatic measurement insignals and images. This topic is also part of the latter research line.

Structuring medical data

In this line of research, work revolves around the CPR. The potential advantages of CPRs as compared to paper-based medical records, are widely recognized (1,2): access at multiple locations, electronic data interchange, decision-support, research, quality assessment, and management support. Still, the design and implementation of CPRs are fraught with many problems. This is especially true for CPRs in specialized care. The greatest challenge is to have medical specialists interactively enter structured patient data at the point of care. Flexibility (e.g., user interfaces tailored to specific needs) must be combined with intuitiveness and efficiency (e.g., minimal navigation effort). Structured data entry is an important area of research in our department. We also investigate the potential of the CPR for shared care, in which the benefits and limitations of electronically sharing patient data among different health care providers are explored.

CPRs for general practitioners (GPs) have shown a much more rapid proliferation, particularly in the Netherlands and the United Kingdom. Presently, most GPs in the Netherlands are using a CPR, not only for their administration but also for patient care. This fortunate situation allows collecting and tracking data of large patient populations to study, e.g., problems related to the post-marketing surveillance of drugs. The design and use of large observational databases to accumulate data of hundreds of thousands of people seen by GPs, is an active area of research in our department.

The high level of computerization of GP practices in the Netherlands also opens possibilities to support the GPs in rationalizing the delivery of health care. One area of research, for example, is to assess whether guidelines-based support systems combined with the

CPR can be instrumental in changing the test-ordering behavior of GPs.

Structured data entry

CPRs hold promise to replace paper records as the primary repositories of clinical information for daily patient care, in addition offering features for management and decision support, quality assessment, education, and research. This promise can only be realized if the clinical narrative (patient history, findings from physical examination, laboratory results, etc.) is stored in an unambiguous, structured format. Therefore, structured data entry (SDE) is the primary focus of research for ORCA (Open Record for CAre), the CPR developed at the Department of Medical Informatics (3,4). The SDE component in ORCA consists of a knowledge base that contains a vocabulary of terms and concepts and lays down how medically meaningful descriptions can be constructed (5). This so-called description knowledge is organized in a tree hierarchy, covering both domain dependent and independent data. Thus, knowledge base contents and structure are separated, allowing the knowledge base to grow and evolve over time without need to change the underlying software. The contents of the knowledge base can be tailored to a specific application domain and maintained with an interactive knowledge editor. The user interface for SDE combines flexibility with efficiency in that it allows dynamically generated context-sensitive forms as well as data entry forms that address specific user needs or preferences. Multilingual support is available and there are numerous options to customize the user interface.

Work on SDE and the ORCA system is carried out in the framework of several national and international projects, such as the European Commission Fourth Framework Programme project I4C (Integration and Communication for the Continuity of Cardiac Care) (6) and the Fifth Framework Health Telematics Programme SYNEX (SYNergy on the EXtranet). Knowledge bases have been or are being developed for such diverse areas as cardiology (7), andrology (8,9), pediatrics, pathology, urology, and severe burn care.

Electronic data interchange

The department is involved in several research projects on electronic communication in health care. In one project, the effects of electronic information exchange between GPs and specialists treating diabetes patients were assessed (10). Based on the EDIFACT standard, a message standard called MEDEUR was defined for electronic communication in a shared care setting (11).

It was shown that frequency of communication and the availability of data to the GP about diagnostic procedures performed in the hospital, were significantly increased using electronic communication. This helps to provide more complete information about the care that patients are receiving. There is evidence that electronic communication between health care providers can also be beneficial for the care of breast cancer patients (12).

In another study, we investigated whether information and communication technology can be used to improve the care of head and neck cancer patients (13). In this TOS (Transmural Oncological Support) project, patients at home and local care providers can electronically communicate with a support team in the hospital, or can consult practical information. The hospital team can also monitor patients, enabling early detection of possible complications or problems in the home environment. The system is currently being evaluated, paying attention to the physical and psychosocial activity of the patients and their use and appreciation of the system.

Message standardization for shared care has also been an important goal in the European Fourth Framework Programme project CoCo (Continuity and Coordination in Health Care), in which our department participated (14). To promote continuity of care in 24 regional health care networks throughout Europe, message implementation guidelines were developed and subsequently implemented.

Finally, use of the Internet for information retrieval and exchange is being investigated. In one study, the quality and reliability of websites offering information on medication to the public were evaluated (15). In another, web technology is used to support access to data on health research and international cooperation, especially for developing countries. This project, called SHARED, was started as a concerted action of the European Commission. Our deparment has developed indexing software to produce keyword profiles for project descriptions. The keywords are obtained from a subset of the Unified Medical Language System's MetaThesaurus. This work elaborates on previous research into the use of UMLS to access CPR data (16).

Post-marketing surveillance

In the Netherlands, almost every citizen is registered in a GP practice. The GP acts as a gatekeeper to the health care system. Patients commonly stay with their GP for many years. Along with the fact that most Dutch GPs have replaced their paper-based medical records with CPRs, this offers a unique opportunity to follow large populations longitudinally, e.g., for post-marketing surveillance (PMS)) of drugs. The IPCI (Integrated Primary Care Information) project was initiated to assess whether CPRs in primary care contain sufficient data to perform PMS studies (17).

While a crucial requirement in the study setup was to secure the privacy of the involved parties, notably patients and GPs, for purposes of data validation, going back to the original data should remain possible. This dilemma was resolved by choosing a setup in which GPs send the patient data to a trusted third party who ensures that the data are made anonymous before being stored in a central database. Under special conditions, a researcher can request additional information from the treating GP through this gatekeeper. A supervisory board, including representatives of the participating GPs, must grant permission for each study which is to be conducted.

To test the quality of the data in the IPCI database, three epidemiological studies were performed to confirm well-known adverse reactions to drugs: the association between the use of ACE-inhibitors and cough (18), antibiotics and skin reactions (19), and fluoroquinolones and tendinitis (20). All these validation studies were able to confirm the positive associations that had been reported previously.

At present, the IPCI database contains information from about 500,000 patients. In the coming years, it will be extended to cover a population of more than one million patients. Future studies will test IPCI for its ability to facilitate randomized trials.

Support of guidelines

The increased availability of blood tests has been accompanied with increasing numbers of inappropriately or inadequately ordered tests by GPs. Two methods were studied to change the traditional paper-based test-ordering behavior of GPs by offering a computerized ordering system, called Bloodlink, integrated with the CPR (21). One method simply restricted the number of tests; the other ordered tests based on the guidelines of the Dutch College of GPs (22). In a randomized trial, the effect of the two methods was compared. Both approaches resulted in reduced number of ordered tests, but the guideline-based approach showed a larger decrease than the one based on restricted choice. Notably, compliance with guideline recommendations was only 39%, but further analysis revealed that many modifications made by the GPs were due to anticipated revisions of the guidelines (23).

Structuring medical knowledge

A second main line of research in our department is concerned with ways to formalize the medical knowledge that physicians are using in their diagnostic or therapeutic decision making. Tools and techniques that result from these investigations have been used to build decision-support systems in a variety of application areas. Evaluation of the performance of the systems that are developed has always been considered an important aspect of our research.

In our research, we are exploring two approaches. One is the more traditional knowledge-engineering approach in which a system developer interacts with one or more domain experts to elucidate and structure the medical knowledge. Of course, aggregated knowledge, as laid down in textbooks or protocol guidelines, may also be taken into account. However, capturing expert knowledge for implementation in computer programs is a strenuous and time-consuming task. The main problem is that experts find it difficult to articulate, in sufficient detail and precision, the rules that they allegedly are using in their decision making. To accommodate this difficulty, learning techniques have been developed that automatically generate decision rules from a set of example cases (e.g., patient data or biosignals). Expert involvement is then reduced to establishing a reference interpretation for each example case before the "learning by example" can take effect. These techniques also allow the discovery of new associations ("data mining") that can further medical insight and improve decision making.

A basic tenet in our research is that users should not have to spend time in providing input data before the system can start its operation. Failure to adhere to this requirement is likely to be an important reason why many previously developed decision-support systems have never gone beyond the prototype stage.

There are at least two ways systems may deliver their decision support. Classically, a system produces an interpretation for each case it is offered. Alternatively, the system follows the user in his or her decision making and only comes into play when the user, according to the system, is making a suboptimal or incorrect decision. Such systems, called critiquing systems, act as a "watchdog"; ideally, they only provide advice if necessary.

Systems that support the interpretation of biosignals or medical images need quantitative measurements to perform their task. Preferably, these measurements are made automatically, requiring signal and image processing. In our department, research into obtaining measurements from biosignals and images has been conducted in different application areas, which will now be described first.

Measuring in biosignals and images

Computerized analysis of the electrocardiogram (ECG) has been one of the focal points of research in our department for many years. We have developed an ECG computer program, called MEANS (Modular ECG Analysis System) (24), which performs ECG measurements and generates a diagnostic interpretation. The performance of MEANS has been evaluated extensively, not only by the developers themselves (24-26) but also by others (27,28). ECG measurements produced by MEANS have been used in several epidemiological studies of the elderly to assess their prognostic value for fatal and nonfatal cardiac events. Measurements studied were heart rate variation (29), T axis (30), QT interval (31), and QT dispersion (32). The measurement of QT dispersion, defined as the difference between the longest and the shortest QT interval in the 12 ECG leads, has been studied in more detail as we had some doubt about the validity of this measurement. We showed that measurement error of QT dispersion is large compared with typical QT dispersion values that have been reported in the literature (33). In another study (34), we explained QT dispersion as an epiphenomenon of T-loop morphology and questioned the intrinsic value of the measurement.

In other work we used ECG measurements for subsequent coding. The Minnesota Code is the most widely used ECG coding system for clinical trials and epidemiologic studies. It has been incorporated in a dedicated version of the MEANS program, MC-MEANS. Initially, MC-MEANS has been tested against a visual coding standard, showing its good performance (35). More recently, we conducted a cooperative study in which coronary heart disease events were used as references (36). The results indicate that MC-MEANS finds significantly more and severer codes than the visual method while maintaining equivalent or increased prognostic significance.

Other biosignal research has addressed the monitoring of ambulatory blood pressure signals. In one study, a method to estimate the nocturnal blood pressure change from the 24-hour blood pressure profile was developed (37). Attenuation of the normal nocturnal decrease in blood pressure is considered a marker of cardiovascular disease. The potential and limitations of the developed method were shown in renal and cardiac transplant recipients. In a sequel to this study, ambulatory blood pressure measurements are combined with measurements of body position and physical activity under ambulatory conditions (38). To this end, a portable activity monitor has been developed. The objective of this study is to gain a better understanding of cardiovascular regulatory mechanisms.

With respect to measurements in medical images, research has been concentrated in two research projects. One study investigated measurements in electron-microscopic images (39). Techniques were developed for the processing and the analysis of electron energy-loss spectroscopic images, taking into account noise and distortions in the image formation process. Electron spectroscopic image analysis has been applied to investigate the storage of iron in liver tissue of hemochromatosis patients and copper accumulation in liver tissue of patients with Wilson's disease (40). Another study aimed at quantifying the changes in the radiographic trabecular bone pattern occurring in osteoperosis (41). Four different texture analysis methods were analyzed, and the effect of noise and image blur was assessed (42).

Recently, our department and the department of Radiology of the University Hospital in Rotterdam have acknowledged the importance of the field of image processing by establishing a joint image processing group. This research group combines expertise and resources from the two departments. Both applied research (e.g., support of MRI intervention and intravascular imaging techniques) and more fundamental research (e.g., segmentation and measurements in images) will be addressed.

Decision-support systems

The diagnostic knowledge incorporated in our ECG computer program MEANS has largely been elucidated following traditional approaches of interaction with expert cardiologists. Classification in MEANS follows a heuristic approach, using comprehensive decision trees (24). In recent research, we investigated the effect of intra-individual ECG variability, such as electrode position shifts, on diagnostic classification, and the use of this variability to improve ECG interpretation (43,44).

As explained above, the main problem with traditional approaches to knowledge elucidation is that experts often find it difficult to express their knowledge in a precise, formal way. Techniques that automatically derive a classifier from a set of labelled examples may be of help, but suffer from at least two difficulties. First, most techniques try to maximize the accuracy of the classifier that is being derived, whereas in medicine a classifier often needs to be optimal with respect to other diagnostic performance measures, such as sensitivity or specificity. Second, the induction process proceeds in a stepwise manner, which may yield suboptimal classifiers. We developed an induction algorithm, called EXPLORE, that allows the user to select one performance measure to be optimized from a set a measurements, and to specify mimimum performance values for the remaining ones (45). The performance of the algorithm was tested on different commonly used data sets, showing its performance to be at least as good as that of other induction methods.

EXPLORE has been used in a project aimed at the development of a program for the interpretation of pediatric ECGs (46,47). EXPLORE is currently being extended to permit user interaction during the rule generation process and to deal with uncertain information.

Other research has addressed the problem of interpreting arterial acid-base data in an intensive care environment (48). Here, a statistical approach was chosen to classify acid-base disturbances (49). The decision-support system was tested in the intensive care units of two Dutch hospitals and compared with existing methods. Superiority of the newly developed system could not be demonstrated, although it was shown to perform better in predicting hospital mortality (48).

Critiquing systems

Above we stressed the need to integrate decision-support systems with CPRs to avoid double data entry by phycisians and to increase chances of the system to be incorporated in a physician's daily practice. In the Netherlands, most GPs are now using a CPR, which allows, in principle, the development of these integrated decision-support systems. In our research, we have been working on critiquing systems that review and generate comments based on the data already available in the CPR (50).

An early system developed was HyperCritic, offering comments to GPs about their treatment of hypertension (51). More recently, another critiquing system, AsthmaCritic, has been developed that reviews the GP's treatment of asthma based on data from CPRs (52). This project was started to study whether the models developed for HyperCritic could also be used in another domain, and to improve the capabilities and quality of the reasoning module. Furthermore, the study aimed to gain a better understanding of the effect of critiques on phycisian behavior. A prototype system has been developed and evaluated using over 100,000 CPRs. About 8,000 records were triggered and subsequently analyzed by the system. AstmaCritic generated an average of three comments per contact. Recently, the system has been updated with the newest guidelines. A randomized field test with 40 GPs has been carried out, the results are currently being analyzed.

Education

The Medical Informatics Department is involved in various educational activities. We participate in the curriculum of the Faculty of Medicine and Health Sciences of the Erasmus University. We are also involved in the postgraduate MSc program of medical informatics that is offered through the Netherlands Institute of Health Sciences.

In our teaching of medical informatics, we make use of the Handbook of Medical Informatics (53), written by a host of experts in medical and health informatics from many countries. The handbook is accompanied by a website that provides the full text of the handbook with hyperlinks to glossary terms and other parts of the book, tables and figures, examples, and questions and answers for self-study (54). Thus, the website forms a convenient vehicle for the support of students as well as teachers and for the dissemination of educational material in the field of medical informatics.

Medical curriculum

Information technology in medicine and health care has shown dramatic changes over the last few decades, but the methods and principles behind the present systems have changed to a much lesser extent. We believe students need to learn a number of basic skills to deal adequately with computers and information systems in their future professional career, but above all they should receive a good appreciation of the possibilities and limitations of information processing in medicine with the use of computers.

The department currently provides courses in the first, second, and fourth year of the medical curriculum. In the first year, an introduction to medical informatics is given in two oral presentations. In three half-day practicals, several computer skills are taught and practiced, e.g., word processing and Internet searching.

In the second year, students practice how to do a literature search and present their results. Students work in teams of three students, each team selecting one of a predefined set of medical research questions that should be answered. The course consists of one lecture and four training sessions to practice literature retrieval with the Internet, word processing, and holding a presentation. In separate sessions, the teams present and discuss the results of their work. Each team also has to submit a concise review paper.

In the fourth year, two lectures and two practicals are given on CPRs. The principles underlying CPRs are taught, and the possibilities and limitations of CPRs are addressed. The difficulties that hamper the introduction of CPRs in routine medical practice are also discussed. During the practical exercises, students receive hands-on experience with several real-life systems and can compare the pros and cons of paper-based versus electronic records.

Postgraduate training

The Department of Medical Informatics is participating in the Netherlands Institute for Health Sciences (NIHES), a joint venture of the Erasmus University Rotterdam, the University of Amsterdam, Utrecht University, and the National Institute of Public Health and the Environment. NIHES offers training in (Clinical) Epidemiology, Health Services Research, Public Health, and Medical Informatics. Via NIHES, a one-year MSc program in Medical Informatics can be followed. In the first semester, students follow introductory courses in the related disciplines of epidemiology, public health, and biostatistics, followed by discipline-specific courses. Our department offers courses on informatics, (advanced) CPRs, decision-support systems, biosignal interpretation, and image processing, for a total of 7 weeks. In the second semester, students must conduct a research project in the field of medical informatics.

Concluding remarks

We have described the research and education in medical informatics at the Faculty of Medicine and Health Sciences of the Erasmus University in Rotterdam. Many of our research projects are done in close national or international collaboration with other medical and health care specialty groups. This illustrates the multidisciplinary nature of the field of medical informatics. We strongly believe our research can and should benefit from such multidisciplinary endeavors (55).

At present, students at our university only receive a minimal education in medical informatics, and the situation is not better at many other universities. One reason may be that medical informatics has not been perceived as important enough to earn a prominent position in medical curricula that are already overly full. This obliges us, perhaps with even more vigor than in the past, to demonstrate the relevance of medical informatics for the practice of health care.

As for the future, we believe the topics in our current lines of research will continue to offer many challenging problems. However, other, new challenges are ahead. For example, telematics, and especially, the use of the Internet have the potential to revolutionize our health care delivery system and to change the relationship between health care providers and patients (56). Achievements of molecular biology and genetics would have been unthinkable without bioinformatics, and the promise these fields have to revolutionize medicine will require solving many more problems also related to medical informatics. We see it as our challenge, whenever possible, to initiate and to participate in multidisciplinary research in these new, exciting fields.

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