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Biomedical Informatics Research for Individualized Life-long Shared Healthcare

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Aim: We developed a multimedia electronic health record MUDR and introduced it to the field of cardiology and dental medicine. We developed a graphical component called DentCross supported by automatic speech recognition connected to an electronic health record (EHR) in dentistry. Platform for semantic interoperability was designed utilizing international communication standards.
Methods: Our approach consisted of three main steps.
1) Development of the multimedia distributed electronic health record MUDR,
2) Development of the interactive graphical DentCross component with automatic speech recognition connected to electronic health record in dentistry.
3) Development of minimal data model for cardiology (MDMC) as the base for studying semantic interoperability issues.
Results: Dental health data for more than 100 patients were collected using EHR with the DentCross component, the DentCross component was used in forensic dentistry and for e-learning activities. We found that approximately 85% of the MDMC concepts are included in at least one classification system. More than 50% of MDMC are included in the SNOMED Clinical Terms.
Conclusions: Structured representation of information in EHR and use of international standards, classifications and nomenclatures is a necessary prerequisite to semantic interoperability issues as well as to an automatic speech recognition.

K e y w o r d s: electronic health record, semantic interoperability, dentistry, cardiology

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1. Introduction

Healthcare is an information-intensive sector. The need to develop and organize new ways of providing health information, data and knowledge has been accompanied by major advances in information and communication technologies. New technologies speed up an exchange and use of data and knowledge and eliminate geographical and time barriers. These technologies influence the healthcare and traditional ways how to work with data and knowledge. Data represent images of the real world in abstract sets. With aid of symbols taken from such sets, data reflect different aspects of real objects or processes existing in the real world. Data are mostly defined as facts or observations. Insufficient standardization in medical terminology presents one of the prevailing problems in processing of any kind of medical-related data. More than ten synonyms may often be found for a single medical term. And even more significant problem arises when the "synonyms" are not fully semantically equivalent or when they are generally understood in different ways. Usage of such synonyms in scientific terminology leads to inaccuracy and misunderstanding. Various classification systems, nomenclatures, thesauri and ontologies have been developed as a result of common endeavour directed to the unification of medical terminology. Unfortunately, the fact that there are more than one hundred of incompatible systems brings complications. The necessity of software tools supporting conversion between major classification systems and recording relations among terms in heterogeneous sources became obvious. Apparently, the most extensive project addressing these issues is the Unified Medical Language System [1]. One of its main components – the UMLS Knowledge Source Server – was used to evaluate the applicability of international nomenclatures for shared healthcare in the Czech Republic.

New requirements to collect data in healthcare efficiently are based on an electronic health record (EHR), where information is stored in a structured form. The paper describes the evolution of the EHR systems called MUDR and MUDRLite that were developed in the EuroMISE Centre. Data entry into the EHR systems during examination of a patient is supported by user-friendly interfaces. For the field of dental medicine we developed a graphical component called DentCross supported by automatic speech recognition. The synergy of the voice control and the graphical representation of data make hand-busy activities in the dental practice easier, quicker and more comfortable. This can result in a better quality of data stored in a structured form in the EHR for dentistry. Moreover, structured information in EHRs can highly support decision-making processes and telemedical applications. The basic requirement for using information from the different EHR systems is their interoperability. Several implementations of EHR using different platforms and techniques were developed and evaluated. Establishing of a required level of semantic interoperability among various systems is not possible without the use of international standards, classifications and nomenclatures. Research and development in the field of semantic interoperability was carried for the field of cardiology. The Minimal Data Model of

Cardiology (MDMC) was used as the semantic base for the most of EHRs developed in the EuroMISE Centre.

2. Electronic Health Record

The Electronic Health Records (EHRs) were classified on the basis of the definition of the International Organization for Standardization (ISO). According to this definition the EHR means a repository of information regarding health status of subject of care in a computer processable form, stored and transmitted securely and accessible by multiple authorized users [2]. Its main goal is to support continuous, efficient and high-quality integrated healthcare using structured data entries [3], interoperability [4] and standards [5], real-time and point-of-care usage [6], privacy enhancing techniques improving security aspects [7, 8], semantic interoperability by ontology based approaches [9] or decision support systems [10]. The ideal EHR system has not been implemented till now, but the evaluation of EHR systems is important [11]. The aspects of information quality most often explored in the studies were the completeness and accuracy of gathered data [12]. The voice commands usage has been experimented with since 1990's [13] as a convenient replacement of a computer control with keyboard and mouse. Necessity of using a human voice to control a computer or other devices arises in typical hands-busy environments such as surgery or dentistry.

The contemporary systems of EHR used as a part of hospital information systems (HIS) in the Czech Republic are mostly free-text based and offer only a limited set of structured data for further automatic processing. Information stored in the free-text based systems is used by a physician during the examination of a patient. Systematic processing of a stored free text is, however, very complicated. The modern EHR systems should offer the possibility to use the stored information for statistical processing or as a data source for decision support systems.

3. Multimedia Distributed Electronic Health Record

The EuroMISE Centre carried out a multidisciplinary research in the field of EHR aimed at the area of highly structured EHRs and interoperability issues, getting experience and inspiration from several European projects, standards and recommendations. The priority was to propose and develop appropriate techniques of data storage, representation and processing aimed at minimizing the effort of users (physicians, nurses) of the system and maximizing the clinical outcome of the collected data. The prevalent application area for our research was the domain of cardiology and dentistry. We developed a voice-supported DentCross component for EHR in dental medicine and studied semantic interoperability in the cardiology domain.

Development of the electronic health record in the EuroMISE Centre started in the year 2000 based on inspirations and experiences from existing CEN/TC251 standards and several European projects, mostly the I4C and TripleC projects [14]. The suggested solution was implemented in a pilot application named "Multimedia distributed electronic health record" (MUDR) [15, 16]. The solution is based on two main structures (data structure and knowledge structure) described using tools of a graph theory. The example of data and knowledge structures in the dental medicine is given in the Fig. 1.

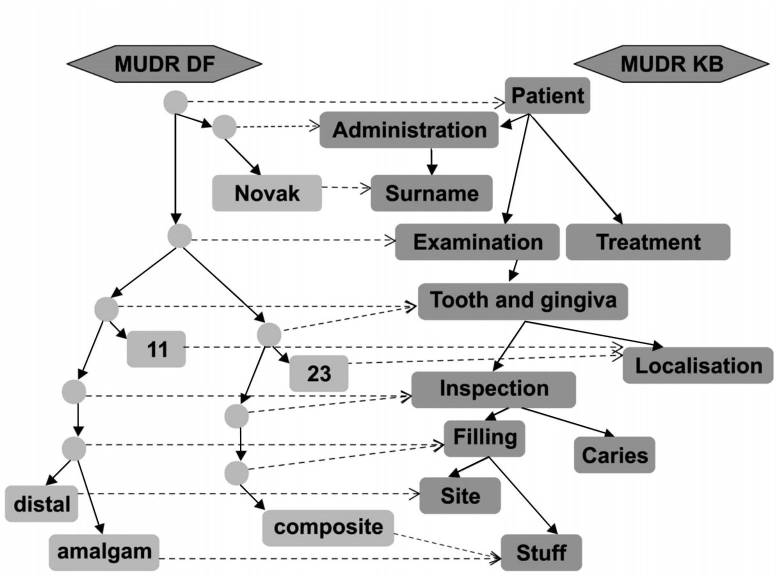

Fig. 1. MUDR EHR data and knowledge graph structures for dental medicine

A specific requirement for the implemented MUDR EHR was the advanced form of a user interface for data entry and presentation. We developed an advanced component representing the dental cross, which is a crucial part of healthcare documentation in the dental medicine. Structuring of information in EHR made possible further development of voice-controlled data entry.

Practical experience from the evaluation of the MUDR system showed that the core of the system is well prepared to serve as a dedicated application server allowing multiple clients to connect and manipulate with stored data. However, implementation of this system in a resource limited outpatients' department of a typical general practitioner is very demanding and difficult. Therefore, we developed a new system with the simplified data storage part and the enhanced part of the user interface. As the new system is derived from the EHR MUDR, we named it MUDRLite [17]. The MUDRLite architecture is based on two tiers. The first one is a relational database (e.g. MS SQL) and the second one is the MUDRLite User Interface layer (MUDRLite UI). The database schema corresponds to particular needs and varies therefore in different environments, as opposed to the fixed database schema in the MUDR data layer.

4. Interactive DentCross Component with Automatic Speech Recognition

To gain acceptance of the MUDRLite's users in the field of dentistry, a highly advanced component, the interactive dental cross, which is a graphic part of dental documentation was developed. The DentCross component is implemented as a stand-alone library DentCross.dll completely developed for the .NET Framework platform. A user-defined component is inserted by the custom element of the MLL with the following mandatory attributes: "dll" specifying the name of the assembly the component is implemented in, and "class" specifying the name of the main class of the included component. This component is fully interactive. A dentist can choose among about 60 different actions, treatment procedures or tooth parameters that are displayed graphically and in a well-organized manner (Fig. 2).

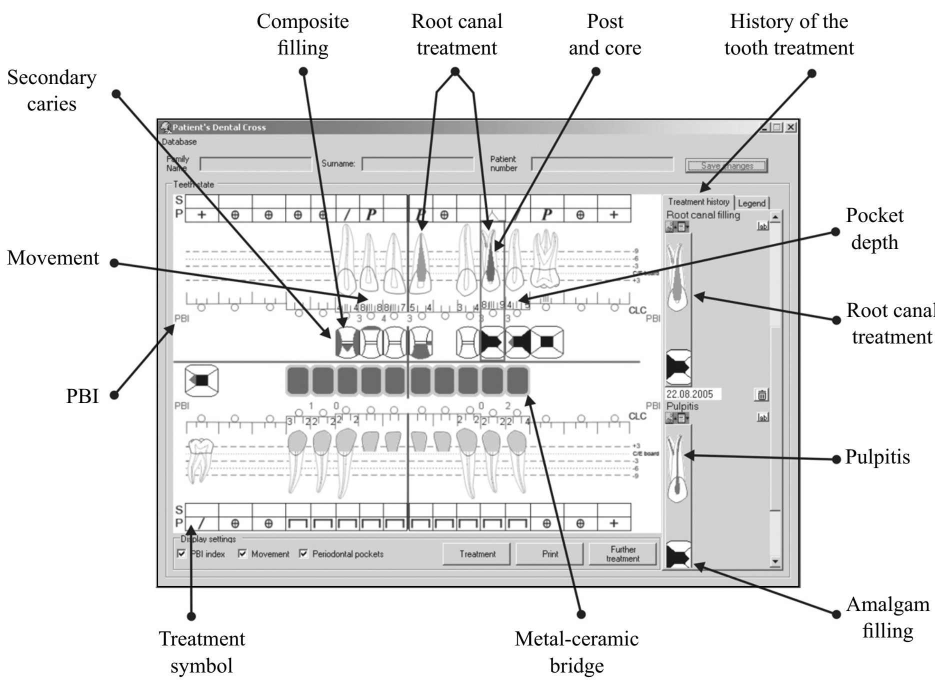

Fig. 2. DentCross component in English to record structured dental information

Necessity of using a human voice to control computer or other devices arose in typical hands-busy environments such as surgery or dentistry. The problems with data storage into the EHR during an examination of a patient led us to further research in the area of the automatic speech recognition in the dental practice. The synergy of the voice control and graphical representation of the dental arch makes hand-busy activities in the dental practice easier, quicker and more comfortable [18].

The automatic speech recognition (ASR) engine was implemented as a standalone application, running in the server-mode in the background.

We will shortly describe three applications of the described voice-supported EHR in the dental practice. Nowadays these applications are evaluated by the Department of Paediatric Stomatology, University Hospital in Motol, Prague.

4.1. Dental Health Documentation

The accomplished analyses of the current state of commercially available software products and patent technologies suggest that the software support for the dental health documentation should be enhanced. The presented interactive DentCross component increases significantly the quality of the dental electronic health record. The graphical design of the DentCross UI is specifically designed to look like a dental arch photo combined with an X-ray image (i.e. root canal or implant picture), PBI, tooth movement, calculus, bone resorption and a periodontal pocket can also be detected. The Department of Paediatric Stomatology introduced the use of EHR with the interactive DentCross component to collect dental health data on patients in the year 2007. Validation of the structured voice-supported data entry in the electronic health record on several real cases in the field of dentistry started in 2008 [19]. Till now the dental health data for more than 100 patients were collected using EHR with the DentCross component.

4.2. Dental Identification

Dental identifications have always played a key role in natural and man-made disaster situations. They take two main forms. First, the most frequently performed examination is a comparative identification which is used to establish that the remains of a decedent and a person represented by *ante mortem* (before death) dental records belong to the same person. The degree of certainty is high. Information from the body assessment or circumstances usually contains clues as to identity of the victim. Second, in those cases where *ante mortem* records are not available and no clues exist to the possible identity, a *post mortem* (after death) dental profile is completed by forensic dentist. Suggesting characteristics of the *deceased person* likely narrows the search for the *ante mortem* materials. Dental identification of humans occurs because of a number of different reasons e.g. criminal, burial, social and in a number of various situations. The victims' bodies of violent crimes, fires, motor vehicle accidents and work place accidents can be disfigured to the extent that identification by a family member is neither reliable nor desirable. Visual identification of persons who had been deceased for a period of time prior to discovery and those found in water is also unpleasant and difficult. Because of the lack of a comprehensive fingerprint and DNA database, dental identification continues to be crucial [20]. Dental structures can provide useful indicators to the individual's identification. The jaws of victims may be exposed and the mandible disarticulated. Using standardized Interpol forms and protocols, a dental chart is compiled and a full mouth survey is made using 14 dental X-ray images. Polaroid photographs are then taken at various magnifications to record any dental anomalies or unique features. The "hard" copies of the radiographs, photographs and dental charting are then reconciled to ensure that no errors have been made in recording the *post-mortem* dental evidence. The dental autopsy is the slowest in the identification process and because of the effect on the facial structures it is the last of the investigative procedures. The DentCross component with automatic speech recognition can be used in Czech and English languages.

4.3. E-learning in Dentistry

Dental health data collected using the voice-supported EHR in dentistry can be used in different e-learning activities at Charles University in Prague. These applications are under development. They are based on different electronic teaching materials for dentistry and the interactive evaluation system ExaME [21].

5. Semantic Interoperability

Our research in the field of semantic interoperability is based on the development of methods and techniques of remote access to information in a form of data and knowledge stored in electronic health documentation. One of the main research tasks is the design, implementation and usability verification of the shared EHR as a tool for continuous shared health care. Among other activities, the open semantic interoperability environment, based on the international standards, ontologies and classifications is designed and implemented, taking into account the national legislative and organization conditions. There were tested two different EHR systems – the pilot implementation of MUDR and the commercial implementation of EHR in the WinMedicalc 2000 HIS [22]. Both systems have a significant part of their information content in the field of cardiology based on MDMC. Several differences in particular implementation of both systems resulted in different representations of the observed data. To establish a required level of interoperability between different systems, a common platform had to be chosen. The International standard HL7 v.3 [23] was selected as this platform. Using the HL7 methodology, the local information models (LIMs) of the participating EHRs were created and necessary mapping of collected variables using the international classifications and nomenclatures was prepared.

5.1. Communication between WinMedicalc 2000 and MUDR EHR Systems

Basic ideas of the process of creation of interoperable environment between the WinMedicalc 2000 and the MUDR EHR systems were presented in [4]. The local information models (LIMs) of both systems (see Fig. 3.) derived from HL7 RIM are conceptually very close to D-MIMs. Moreover, beside the similar concepts both LIMs use also the references to the established code systems (LOINC, NCLP), giving possibility of the precise specification of semantics. From LIMs so called "templates" were derived. Their content is very close to definitions of the HL7 messages written in HMD [23]. Mapping among various attributes representing the same information is also rather simple. Difficulties in the mapping process are caused by the fact that some concepts are represented on different levels in the communicating systems – e.g. in one system as an independent class but in the other system as a subclass, or an attribute vs. a class. Such a situation must be respected in the formulation of transformation rules between the templates and the HL7 messages. At present the rules are supposed to be formulated by the person administrating the communication, so the problems mentioned above can be solved. In any case, the fundamental role in ensuring interoperability of the systems will be played by the mapping component.

5.2. Classifications and Nomenclatures

Uniqueness of the term definitions and their precise denomination are necessary for semantic interoperability. We found that current classification of medical terms is not optimal. Insufficient standardization in medical terminology represents one of the prevailing problems in processing of any kind of medical-related data. Various classification systems, nomenclatures, thesauri and ontologies have been developed to solve this problem, but the process is complicated by the existence of more than one hundred incompatible systems. The most extensive current project that supports conversions between major classification systems and records relations among terms in heterogeneous sources is the Unified Medical Language System (UMLS). During the development of MUDR EHR and MDMC [24], the UMLS Knowledge Source Server was used to evaluate applicability of the international nomenclatures in the Czech medical terminology. During the analysis, we found that approximately 85% of the MDMC concepts were included in at least one classification system. More than 50% are included in the SNOMED Clinical Terms [25]. The concepts may be divided into four classes:

- Trouble-free concepts – only one possibility of mapping exists.
- Partially problematic concepts – there are several possibilities of mapping to different synonyms, which differ slightly in their meanings.

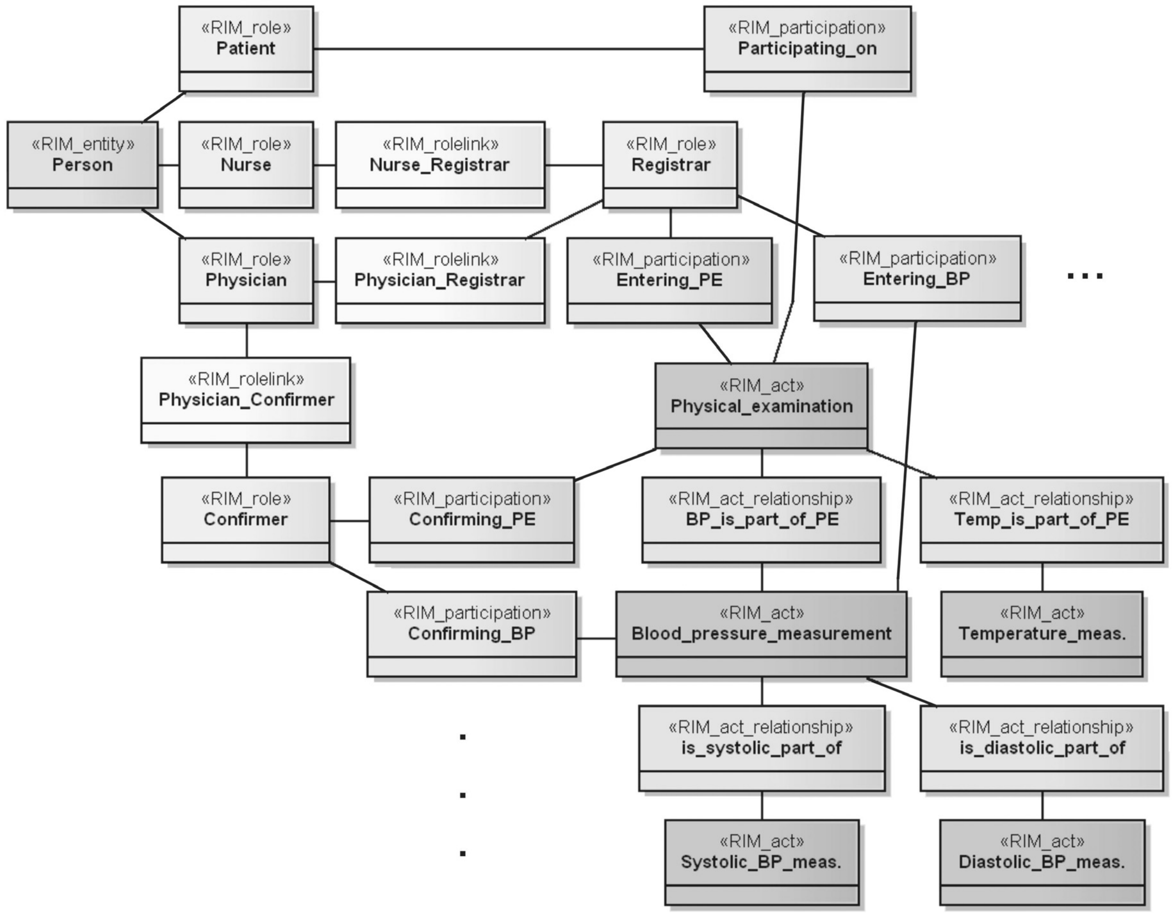

Fig. 3. Selected part of MUDR LIM

- Concepts with a too small or too big granularity.
- Concepts, which cannot be found in any available classification system.

6. Conclusions

Electronic health records support continuous, efficient and high-quality integrated healthcare by providing comprehensive information about individual. They not only keep the data on the individual's current and historical health, medical conditions, tests, treatments or medication, but can also provide more advanced processing of these data and decision support functionality. The structured representation of information in EHR and use of the international standards, classifications and nomenclatures is a necessary prerequisite to semantic interoperability establishment. Because of the highly structured information storage in all of our solutions, the semantically interoperable communication solution was possible. As a tool, we used the HL7 modelling methodology and international classifications to map information models of the different information systems. The development of the EHR system called MUDR demonstrated the advantages of the structured data entry over the free-text entry. The practical usability of the voice-controlled DentCross component for structured data entry in dentistry was shown. To overcome the problems connected with concepts and their mapping to the international classification systems a close cooperation with physicians is required. In some cases it may be possible to add a new concept into an upcoming revision of a given coding system.

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