Electronic Health Record for Forensic Dentistry

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Summary

Objectives: To identify support of structured data entry for electronic health record application in forensic dentistry.
Methods: The methods of structuring information in dentistry are described and validation of structured data entry in electronic health records for forensic dentistry is performed on several real cases with the interactive DentCross component. The connection of this component to MUDR and MUDRLite electronic health records is described.
Results: The use of the electronic health record MUDRLite and the interactive DentCross component to collect dental information required by standardized Disaster Victim Identification Form by Interpol for possible victim identification is shown.
Conclusions: The analysis of structured data entry for dentistry using the DentCross component connected to an electronic health record showed the practical ability of the DentCross component to deliver a real service to dental care and the ability to support the identification of a person in forensic dentistry.

Keywords

Electronic health record, structured data entry, forensic dentistry

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1. Introduction

Many different definitions of electronic health records exist. International standard ISO/DTR 20514:2004 defines the electronic health record (EHR) as a repository of information regarding the health of a subject of care in computer-processible form, stored and transmitted securely, and accessible by multiple authorized users. Its primary purpose is the support of continuing, efficient and quality-integrated health care. Therefore EHR contains all patient medical information from multiple sources, which is retrospective, concurrent and prospective. In addition, EHRs may contain data about medical referrals, medical treatments, medications and their application, demographic information and other non-clinical administrative information. The main goals of electronic health records are to support continuing, efficient and high-quality integrated health care by sharing patient health information between authorized users. Optimally, the EHR should have the following characteristics:

- patient-centered: one EHR relates to one subject of care, not to an episode of care at an institution;
- longitudinal: it is a long-term record of care, possibly from birth to death;
- comprehensive: it includes a record of care events from all types of caretakers and provider institutions tending to a patient, not just one speciality; in other words there are no important care events not stored in the EHR;
- prospective: not only previous events are recorded, but all decisions and prospective information such as plans, goals, orders and evaluations are given.

In the ideal situation, the information in an EHR is continuously updated and current. Terms commonly used in describing the EHR include interactive user interfaces and structured data entries [1, 2], interoperability [3] and standards [4, 5], real-time and point-of-care usage [6], privacy enhancing techniques improving security aspects [7], [8, 9], semantic interoperability by ontology-based approaches [10, 11] or decision support systems [12, 13]. The EHR allows collection of data for other reasons than for direct patient care, such as quality improvement, outcome reporting, resource management, and public health communicable disease surveillance. The ideal EHR system has not been implemented by any software or other vendor, but the evaluation of EHR systems is important [14].

2. Multimedia Distributed Electronic Health Record

Development of the electronic health record at the EuroMISE Centre, Institute of Computer Science AS CR 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 [15]. The main requirement for the proposed system was the structured way of data storage combined with free text with possibility of dynamic extension and modification of the set of collected attributes without any change of the data-

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base structure. The main goal of the research in this field was to suggest common general principles to increase the quality of EHR systems, to simplify data sharing and data migration among various EHR systems and to help to overcome the classical free-text- based information stored in medical records. The suggested solutions were implemented in a pilot application named "MUltimedia Distributed Record" (MUDR) [22, 23].

The main architecture of MUDR EHR was based on a 3-layer architecture – database layer, the application layer and the user interface layer. Because of the requirement of a dynamically extensible and modifiable set of collected attributes, it was complicated to use a classical relational database structure with columns corresponding to the gathered features as the basis of information storage. The solution is based on two main structures described by tools of graph theory. The example of data and knowledge structures in dental medicine is given (Fig. 1).

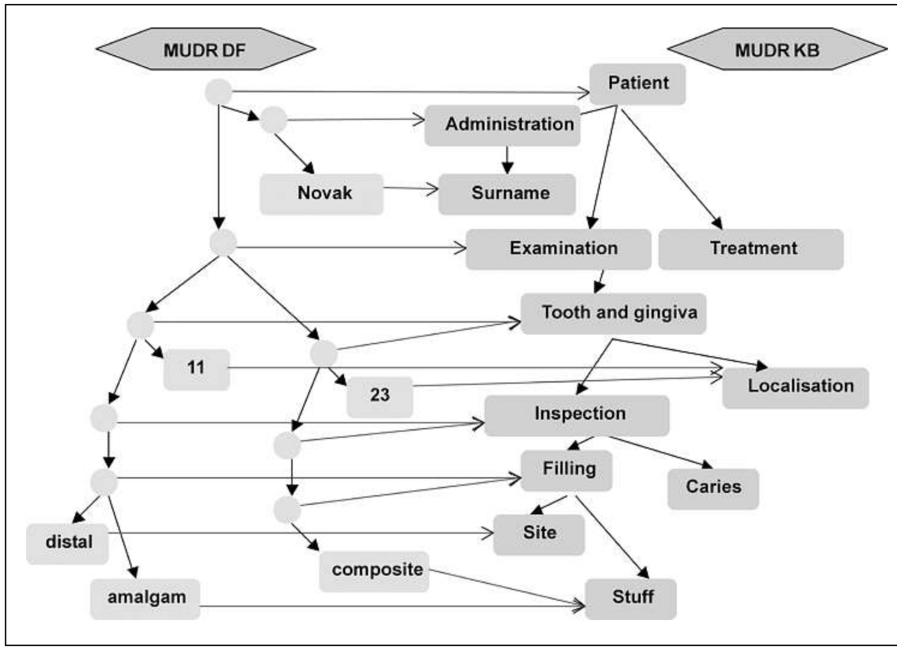

Fig. 1 Example of MUDR EHR data and knowledge graph structures in dental medicine

The set of collected attributes and relations among them are stored in a directed graph structure called a knowledge base. The vertices of the graph describe the collected attributes by their unique id, internal name, physical data type and other auxiliary information; the graph edges describe the relations among attributes. The dominant edge of type "inferior" exists in the graph. This edge defines the hierarchical tree structure of the knowledge base, so that the knowledge base can be described by directed forest with a few trees. These trees are also called "knowledge base domains". Another hierarchical graph structure named "data-files" is used to store the patient data itself. Each tree in the graph describes the data of one patient. Each vertex in the tree describes one instance of the medical concept from the knowledge base by the identification of the concept (internal name of the vertex), its value (with the possibility to specify the range of values), date and time of examination and other administrative data. The values are physically stored in separate tables according to the physical data type.

The application layer consists of four basic components – the HTTP server used for communication with client applications, the EHR-AppL service implementing the main application logic, the CGI-script (potentially more of them) serving as an interface between HTTP server and the EHR-AppL service and possibly medical guidelines modules. The application layer realizes the set of functions provided to the client application and realizes the functionality of the EHR system on a more abstract level by isolating clients from database implementation details. This solution enables the change of the used database in the future without influencing client applications and helps to achieve a higher level of safety and security. The communication between clients and the application layer is done by a secure HTTPS protocol (Hypertext Transfer Protocol). The HTTP server is therefore the necessary part of the application layer. This approach opens the possibility to create special CGI-scripts for communication with lightweight clients like web or wap browsers, enabling the use of mobile devices to connect to the EHR. An important attribute of an EHR that is improving the effectiveness and quality of physician's work during data entry is a decision support capability. Application layer of MUDR supports the decision support functionality by modules implementing algorithms, for example algorithms described in medical guidelines for the management of hypertension [29].

When designing a system, two types of its usage should be taken into account – consultation and data entry. Consultation requires minimal search time, an inspectional way of information presentation, problem-oriented grouping of findings and patient visits. Data entry requires the maximal ease and speed of process of entering the data into the system. The development of the user interface of MUDR EHR focuses on both parts – data entry and consultation. The client application implements the functionality of structured data entry combined with free text, including the tools for the formalization of free text. The structured data can be entered either directly by selecting the appropriate items from the tree structure of the knowledge base or by using dynamically created forms. The printable reports and user entry forms are created dynamically following the definitions in XML documents. The consistence of the entered data can be checked by the mechanism, controlled by the set of consistency rules. The application utilizes the guideline module part of the application layer of the MUDR EHR and shows either the text of selected guideline or starts the process of consultation of the selected patient's data with the guideline module.

Practical experiences from the evaluation of the MUDR system showed that the

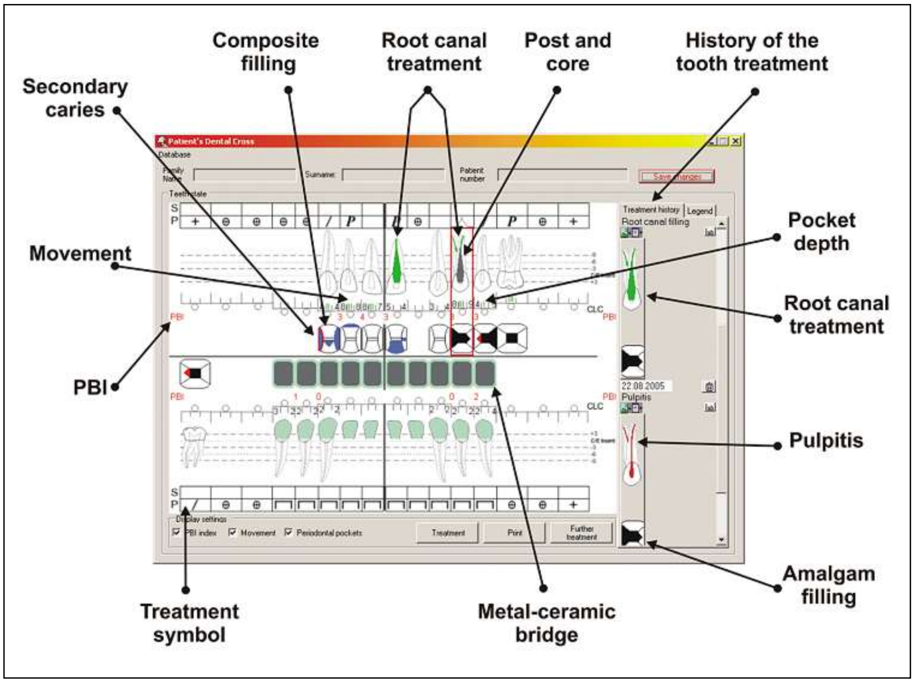

Fig. 2 The use of the DentCross component to record structured dental information

core of the system is well prepared to serve as a dedicated application server allowing multiple clients to connect and manipulate stored data. However, the implementation of this system in a resource-limited office of a typical general practitioner is very demanding and difficult. Therefore, we developed a new system with simplified data storage and an enhanced user interface. Because the new system is derived from the EHR MUDR, we named the new system MUDRLite.

3. MUDRLite

The MUDRLite architecture is based on two tiers. The first one is a relational database (e.g. MS SQL) and the second one is a MUDRLite User Interface layer (MUDRLite UI). The database schema corresponds to particular needs and therefore varies in different environments, as opposed to the fixed database schema in the MUDR data layer. Thus, a basic way to share the healthcare data is to use this client-server architecture, install more user interfaces and access the data through a common database. However, this is not the issue we are currently concerned with because it would share data just in a single environment within homogenous applications. What we would like to support is a sharable electronic health record among various heterogeneous applications based on standards defined to communicate the structured contents of the EHR.

The core of MUDRLite – MUDRLite Interpreter – is able to handle various database schemas. This feature often simplifies the way of importing old data stored in other databases or files. The visual aspects as well as the behavior of the MUDRLite UI are completely described by an XML configuration file. The end-user can see a set of forms with various controls placed on them by appropriate XML elements. MUDRLite operates as a kind of commands' interpreter; it processes the instructions encoded in MLL language as described in [24] and manipulates the database layer as well as the visual aspects of the MUDRLite UI.

As the set of predefined controls is limited, MUDRLite provides interfaces to include user-defined controls and components. These interfaces can be used to offer graphically and functionally advanced components as well as new features, e.g. an advanced security policy, integration with other existing information systems, or sharing of electronic health data based on standardized EHR communications. If such a user-defined component is trusted, it gets the access to the structured EHR. However, this access can be prohibited or limited by the MUDRLite Interpreter for security reasons in accordance to a defined security policy. Anyway, the MUDRLite Interpreter may be able to monitor the access and create a record concerning all the read/write actions. By virtue of the interfaces, a trusted component can access the data in the EHR and thus it serves as a kind of "intelligent proxy" implementing a standardized EHR communication.

4. Interactive DentCross Component

The first practical implementation of the MUDRLite system was in the area of dentistry. A specific requirement for the implemented EHR instance was the advanced form of a user interface for data entry and presentation. The main part of the user interface is represented by a so-called dental cross – the graphical schema of dental arcs, divided by quadrants and showing the results of all examinations and treatments for each tooth. This kind of functionality could not be realized by the standard set of visual controls and components of MUDRLite, therefore a special component named DentCross (Dental Cross) was developed. The DentCross component is implemented as a stand-alone library DentCross.dll that was completely developed for the NET Framework platform using the Microsoft Visual Studio.NET 2003 development tool. For the end-user the DentCross component looks like a kind of a dental orthopantomogram. This component is fully interactive and enables recording fully structured dental information that can be inserted in a user-friendly way either by mouse or keyboard (Fig. 2).

A dentist can choose among about 60 different actions, treatment procedures or tooth parameters that are displayed graphically and lucidly. The features of the component include the support of various forms and shapes of teeth, the exact position of a tooth, impacted teeth, agenesis of a tooth, primary and secondary caries, filling of a tooth, pulp and periodontal pathology, root canal treatment, inlay, onlay and overlay, post and core, crowns, partial veneer crowns, bridge(s), dentures – complete denture, over denture, as well as removable partial dentures, implants, dent alveolar surgery, calculus, PBI, movement of a tooth, periodontal pocket, bone resorption, temporomandibular joint, etc. The DentCross component includes a treatment plan combined with a calendar that enables scheduling the patients' visits and treatments. Data structuring is on a relatively low level and it is given by the filling characteristics of pre-printed forms, which include more or less standardized symbols (e.g. "/" for caries, "-" for pulpitis, or "x" for a tooth to be extracted). Symbols are placed in the section corresponding to a particular tooth. Recently, this technology was applied for a Czech national patent under the No. PV 2005–229. This advanced form of health documentation will lead to easier and more complex treatment evaluation based on the bigger amount of relevant information, which is stored transparently using the Interactive Dental Cross Component. This tool helps to create the transparent part of the EHR on the whole dentition and individually accomplished examinations. The information recorded in a graphical form accelerates dentist's decision-making and it enables a more complex view in suggesting an evaluation. Another very important use of structured dental information is in the field of forensic dentistry. We will further demonstrate how to use the information collected by the interactive DentCross component to support the identification in forensic dentistry.

5. 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 are the same individual. The degree of certainty is high. Information from the body assessment or circumstances usually contains clues as to who has died. 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 the forensic dentist. Suggesting characteristics of the individual likely narrow the search for the ante mortem materials [16]. Dental identification of humans occurs because of a number of different reasons i.e. criminal, burial, social etc. and in a number of various situations [25]. The victims' bodies of violent crimes, fires, motor vehicle accidents and work place incidents can be disfigured to the extent that identification by a family member is neither reliable nor desirable. Persons who have been deceased for some time prior to discovery and those found in water also present unpleasant and difficult visual identifications. Because of the lack of a comprehensive fingerprint and DNA database, dental identification continues to be crucial. 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 the dental charting are then reconciled to ensure that no errors have been made in recording the post-mortem dental evidence [26]. The dental autopsy is the slowest in the identification process and because of the effect on facial structures it is the last of the investigative procedures.

There is a special form named Disaster Victim Identification Form [17] designed by Interpol used for victim identification in practice. An electronic version of this form exists and is called DVI System International [27]. The program covers all parts of the paper-based DVI forms. The user may select different languages for the user interface. A very strong feature of the system is the possibility of doing a number of advanced searches in all entered data, including dental records and DNA. Automatic batch matching of dental and DNA data can be used as well. The program can be deployed as a national register of missing and unidentified dead persons. Announcements to other countries of searches and of persons found can be made electronically to the recipient countries using the DVI system. The system may print complete DVI form sets in various languages (English, French, Spanish, Norwegian, Dutch, Swedish, Icelandic and Danish). The application operates under Windows 2000/XP or higher. It is implemented using the Delphi 6.0 integrated development environment and data storage is provided by Microsoft SQL Server 2000 MSDE/Standard [28].

A range of conclusions can be reached when reporting a dental identification. The American Board of Forensic Odontology [18] recommends that these are limited to the following four conclusions:

1) Positive identification: the ante mortem and post mortem data are matched in sufficient details, with no unexplainable discrepancies, to establish that they are from the same individual.
2) Possible identification: the ante mortem and post mortem data have consistent features but, because of the quality of either the post mortem remains or the ante mortem evidence, it is not possible to establish identity positively.
3) Insufficient evidence: the available information is insufficient to form the basis for a conclusion.
4) Exclusion: the ante mortem and post mortem data are clearly inconsistent.

The forensic dentist produces the post mortem record by careful charting and written descriptions of the dental structures and radiographs. Once the post mortem record is complete, a comparison between the two records can be carried out. A methodical and systematic comparison is required, examining each tooth and surrounding structures in turn [19, 20].

6. Identification Support by Interactive DentCross Component

Accomplished analyses of the current state of commercially available software products and patent technologies suggest that the

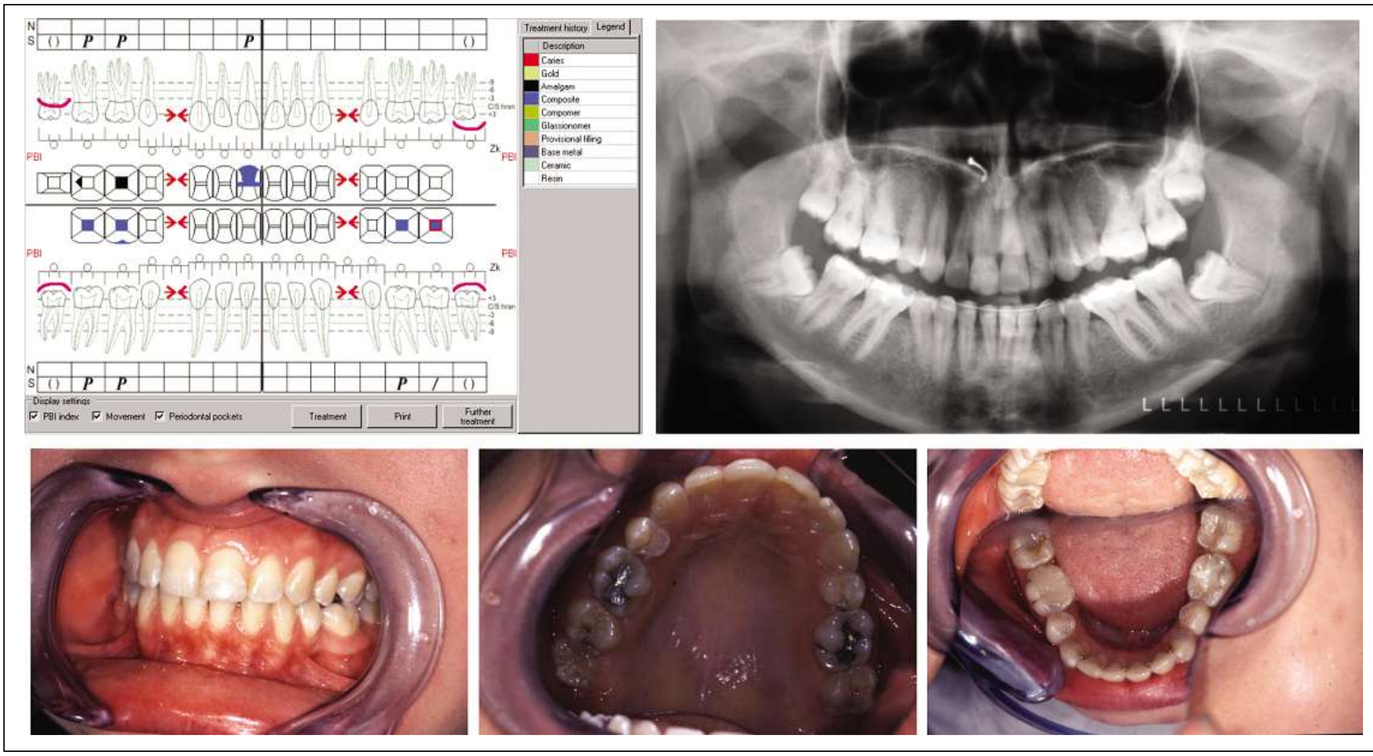

Fig. 3 Patient with numerous restorative treatments (DentCross record, X-ray image and photos)

software support of keeping dental health documentation is on a relatively low level [17]. The new technique significantly increased by implementation of interactive DentCross components. DentCross graphically looks like a kind of a dental arch photo and X-ray image (i.e. root canal or implant picture).

Clearly, individuals with numerous and complex dental treatments are often easier to identify than those individuals with little or no restorative treatment. Interactive DentCross component helps us to analyze secret findings (Fig. 3). PBI, tooth movement, calculus and periodontal pocket can be also detected, however these types of examinations cannot be provided in victims. On the other hand bone resorption can be also detected and could help in comparison with an X-ray image.

To use the dental information required by standardized Disaster Victim Identification Form by Interpol for possible victim identification, the data from the EHR should be made available in the electronic form for the DVI System International, operated by the forensic dentist. For these purposes MUDRLite disposes of interfaces enabled to connect graphically and functionally advanced components [21]. One of such tools might be Import/Export Connector between MUDRLite working with the DentCross component and DVI System International. This connector makes it possible to use the former system (the DVI System International) with its advanced searching techniques and acceptance among forensic experts together with more detailed dental data structuring using the DentCross component. This connector could be implemented as a component in MUDRLite that would produce output data in such a format that could be imported into the DVI System International. This solution can help data structuring in forensic dentistry and contribute to sharing of structured data among heterogeneous health information system.

7. Conclusions

Electronic health records support continuing, efficient and high quality integrated healthcare by providing comprehensive information about the 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 development of the EHR system called MUDR demonstrated the advantages of structured data entry before the free-text entry used in MUDR and MUDRLite EHR systems. The practical usability of the DentCross component for structured data entry is shown.

The MUDRLite EHR with the interactive DentCross component brings transparent health records to the whole dentition and accomplished examinations of a patient in a concentrated form. The dental information recorded in a common graphical structure accelerates dentist's decision-making and provides a more complex view of gathered information. This approach can not only simplify the recording of structured dental data in daily dental practice but it also can support disaster victim identification in forensic dentistry. This approach plays a major role in the identification of those individuals who cannot be identified visually or by other means. The unique nature of our dental anatomy and the placement of custom restorations ensure sufficient accuracy when the techniques are correctly employed. The described application of MUDR EHR with the DentCross component thus opened new possibilities of storage and classification of data in dental medicine.

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