Addressing critical issues in the development of an Oncology Information System

D. Urda[a], N. Ribelles[b], J.L. Subirats[a], L. Franco[a], E. Alba[b], J.M. Jerez[a,*]

[a] Department of Computer Science, ETSI Informática, University of Málaga, Spain
[b] Department of Medical Oncology, Hospital Universitario Virgen de la Victoria, Málaga, Spain

ABSTRACT

Purposes: This paper presents the experience on the design and implementation of a user-centered Oncology Information System developed for the Medical Oncology Department at the "Hospital Universitario Virgen de la Victoria", in Málaga, Spain. The project focused on the aspects considered in the literature as critical factors for a successful deployment and usage of a health information system.
Methods: System usability, adequate technology, integration of clinical routines, real-time statistical analysis of data, information confidentiality and standard protocol-based external interconnection were the key aspects considered.
Results: The developed system is based on a web application with a modular and layered architecture accounting for usability, ease of maintenance and further system development. Evaluation of system usability was carried at three and fifteen months after system deployment to analyze the advantages/disadvantages experienced by the end-users.
Conclusions: A thorough prior analysis of clinical activities and workflows, the use of the adequate technology, and the availability of data analysis tools will almost guarantee success in the deployment of an Oncology Information System.

© 2012 Elsevier Ireland Ltd. All rights reserved.

1. Introduction

Electronic health records (EHRs) are medical history data that contain information and documents in an electronic format and can thus be accessed, processed, transmitted and displayed using appropriate Information and Communications Technologies [1,2]. Using EHRs improves the quality of care, diminishes dangerous medical errors and helps control costs [3–5]. Nevertheless, applying health information technology to patient health data recording is not as widespread as one may expect, despite its capacity to improve the efficiency and effectiveness of health care [3,4,6,7]. Initiatives by different national health services have yet to reach sufficient adoption levels [8–10], although primary care practice is one exception [11].

Several circumstances are associated with insufficient EHR use, including suboptimal technology and potential user resistance [12–14], the lack of integration of requirements, interfaces and procedures into routine clinical practices [15–17], insufficient information transmission among different health information systems (HISs) [18,19], and the absence of User-Centered Design approaches in the systems' development [20]. Addressing these deficiencies in the HIS developmental process should allow software designers to reach the final HIS goal: improve and achieve not only better technology but also better medicine [20].

* Corresponding author. Tel.: +34 952132895; fax: +34 952131397.
E-mail addresses: durda@lcc.uma.es (D. Urda), nuriaribelles@gmail.com (N. Ribelles), jlsubirats@lcc.uma.es (J.L. Subirats), lfranco@lcc.uma.es (L. Franco), emilioalbac@gmail.com (E. Alba), jja@lcc.uma.es (J.M. Jerez).
URL: http://www.lcc.uma.es (J.M. Jerez).

In the oncology field, clinicians also demand the electronic collection of cancer-related information and data [21], seeking to practice personalized medicine and fulfill prospective/retrospective real-time clinical research studies, thus advancing high-quality cancer care. In this sense, the American Society of Clinical Oncology (ASCO) has recently recognized the essential role of EHRs in advancing the quality of care for oncologic patients [22–25]. Specific issues have been clearly outlined in the Clinical Oncology Requirements for the EHR (CORE) document developed by ASCO in collaboration with the National Cancer Institute (NCI) [26].

This paper reports an experience in the software development process of a User-Centered Design for an Oncology Information System (OIS), as a specific HIS software, focusing on aspects mentioned by practitioners to make the system more user-friendly and useful in their daily tasks. The system, designed using several new technologies, is based on a web application with a modular and layered architecture, while accounting for usability, ease of maintenance and further system development.

Among the modules that the system incorporates according to the oncology unit's requirements, a powerful statistical tool was introduced, allowing users to perform survival analysis in real time. This tool saves the clinicians from the demanding tasks of selecting the patients to be included in a clinical research study and exporting the data to a survival analysis software package, similar to SPSS,[1] R,[2] or STATA.[3]

The aim of the present work is to report the overall experience of implementing an OIS at the Medical Oncology Department (MOD) in the "Hospital Universitario Virgen de la Victoria" (HUVV) in Málaga, Spain. We discuss the early stages when the system requirements were analyzed. The final users' opinions were evaluated over a two-year period. All the intermediate stages are examined when describing the different technologies applied.

The remainder of the paper is structured as follows: Section 2 provides a detailed overview of the system, Section 3 describes the methodologies used, Section 4 presents a survey evaluating the OIS, and Section 5 discusses the results obtained and presents the conclusions.

2.   OIS overview

The OIS was first deployed at the Medical Oncology Department in the HUVV in late 2009. This hospital is a medical center in Málaga, Spain, and includes 732 beds and approximately 475,915 patients (data from 2008). The system is the final result of an intense 3-year collaboration between the "Computational Intelligence in Biomedicine" (CIB) research group from the University of Málaga and the HUVV, and incorporates information from different clinical cancer databases managed by the oncology service staff from 1978 to 2007.

The main purpose in developing the OIS was to provide different utilities that reflect the working methodology of the paper-based records as closely as possible, without forgetting
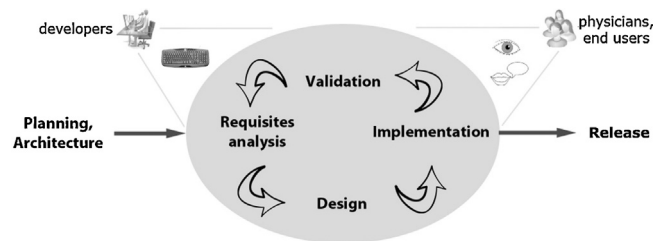

Fig. 1 – OIS development process, where end users have important participation, providing constant feedback to developers in the four process phases: analysis, design, implementation and validation.

that the new system should incorporate tools to allow further modifications and expansions, according to the end users' future requirements. The ultimate goal of the OIS was to systematize and unify the daily work of the entire cancer care unit, facilitating their labor and incorporating new useful online statistical tools.

To allow information management by the MOD personnel from other departments within the hospital, a web design was considered and evaluated as the more appropriate platform. The system design should consider the privacy and confidentiality of the information managed as a priority, and should provide the necessary tools to retrieve, manipulate and save the information in the MOD. The system should also provide quick response times for every process offered by the application, as it is expected to operate in real-time by several users.

The OIS functionality architecture was structured in five top-level modules, namely Patients Manager, Treatment Outpatient Unit, Clinical Research, Genetic Counseling, and Statistical Analysis (Fig. 2).[4] User Access Control and Database Management modules were also implemented to manage users' roles, activity and errors logs. In an effective collaboration among clinicians and designers, great efforts were taken to define the key information that connects the different system modules to guarantee real-time information exploitation, coherence and integrity in information updating and overall system usability.

3.   Methodology

As mentioned above, critical factors when developing an OIS are adequate technology use, integration of requirements and procedures into clinical practices, efficacy in information transmission between different systems, and a user-centered/user-friendly design, among others.

3.1.   User-Centered Design approach

Several authors [27,28] describe how a User-Centered Design (UCD) is widely considered the key to product usefulness and usability, and, in particular, the work reported in [20]
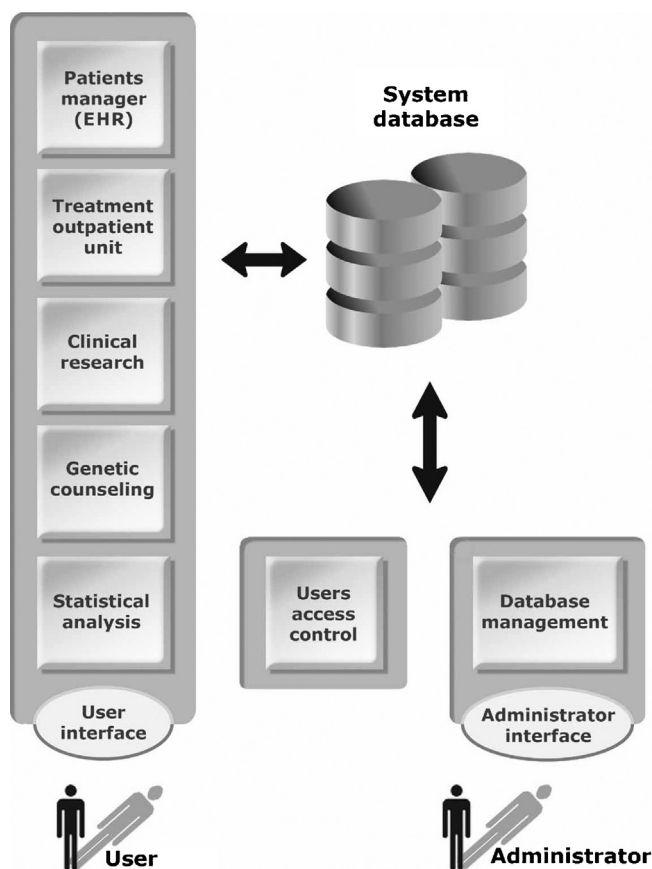

Fig. 2 – Functional top-level OIS modules.

focuses on applying UCD to HIS design and development. A UCD approach accounts for the following principles: active user involvement for a clear understanding of user and task requirements, iterative design and evaluation, and a multi-disciplinary approach. A UCD approach increases OIS efficiency while decreasing physicians' workloads, a factor that directly affects the level of system adoption [6,29–31].

Fig. 1 shows the spiral software development model used in the OIS design and implementation. It is important to highlight the iterative and incremental procedure that involves both the project management team and several medical oncologists from the HUVV (hereafter also referred as medical personnel or end users). In this step, the release is incrementally developed throughout the four classical software engineering phases: requisites analysis, design, implementation and validation. A key factor to ensure project success is the active participation of end users during all phases, which provides constant feedback to the project management team, allowing the usefulness and usability of the release to increase. The spiral model allows designers to obtain new releases of the system after an entire cycle (requisites analysis, design, implementation and validation) is completed. The project management team implemented cycles of three months of duration, so that in this short periods of time a new stable release was deployed in the hospital.

A web-based public cost-free application (Google Docs[5]) was utilized during the development process to share documents between the system's developers and end users. The Software Requirements Specification (SRS), containing a complete description of OIS behavior, was performed in collaboration with the end users, including a set of cases that describe the interaction process that users were to expect to have with the software. Microsoft Expression Studio was used to rapidly develop effective web prototypes to present ideas, user interface flows, screen layouts and application functionality to the end users, thus enabling efficient and constant feedback.

We next describe the characteristics and most relevant and critical details of the modules shown in Fig. 2 for which several aspects were considered to confer integrity, coherence and real-time response to the OIS:

- The Patient Manager module manages and coordinates all processes associated with patient care and gathers clinical notes from the various consultation types available. This module collects information from patients and others, regarding the date of diagnosis, type of neoplasm, location, stage, type and intention of oncology treatment proposed, and the condition of the last follow-up statement. Each option is associated with its corresponding code according to the International Classification of Diseases (ICD-9) [32]. It is also possible to collect information on toxicity presence in patients following the CTCAE grading system's coding [33].
- The Treatment Outpatient Unit module manages the daily activities that occur in the Treatment Outpatient Unit and allows the issuance of periodic reports to the Administration authority, in this case the Andalusian Health Service ("Servicio Andaluz de Salud" (SAS)). All procedures performed on each patient can be included in two different tabs: Treatment Administration or Other Procedures. The listed options comprise nearly 200 different types of treatments that are easy to update and other procedures that can be performed in the Outpatient Treatment Unit. Each activity is associated with its corresponding ICD-9-CM Procedure Code and Supplementary V Code [32].
- The Clinical Research module manages patient information included in clinical trials (e.g., dates when the consent form was signed, names of the physician and database manager responsible for the clinical trial). This utility also provides easy access to all information concerning each clinical trial, including assessment schedules, eligibility criteria, study treatments, dose-modification criteria or lists of forbidden concomitant medications. The stored data can also identify patients for future clinical trials [26,34]. Beyond this usefulness, the physician's ability to access information in real-time from any location within the hospital motivates and increases their participation in the studies [26].
- The Genetic Counseling module contains the appropriate procedures for collecting information regarding family trees and specific types of medical genetics consultations.
- The Statistical Analysis module incorporates several utilities that allow clinicians to perform real-time statistical
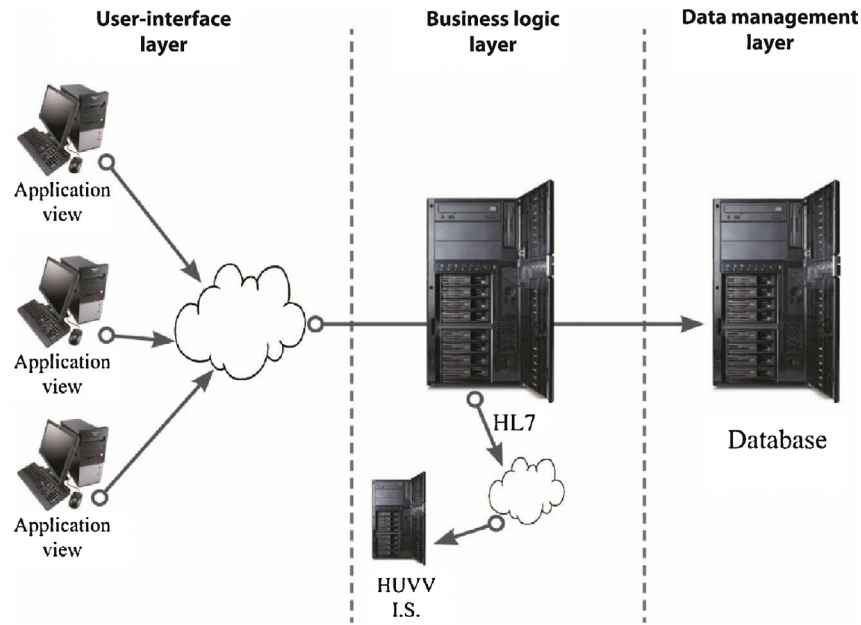
---

5 http://www.docs.google.com/.

Fig. 3 – A 3-layered system architecture was used for the OIS, creating a logical division between the user-interface, business logic and data management layers.

analysis on the information contained in the database. A powerful search engine is available to select patients who satisfy one or more common search criteria to be included in retrospective or prospective clinical studies.

- The User Access Control module guarantees information confidentiality, preventing anyone who is not registered in the system from accessing the contained information. A sign-in page controls accessibility (requiring a username and password), defining different user profiles with specific privileges and limitations.
- The Database Management module allows system management through a web-based application. It provides different tools to manipulate the content of tables in the database (e.g., adding, modifying or deleting a user from the system). Moreover, this module provides a complete and detailed registry of every transaction occurring in the OIS, identifying possible errors and permitting information recovery.

3.1.1. Successful incorporation of previous information

In a real scenario, a large amount of critical information is usually stored in different database formats for oncology services. Integrating this information into the new OIS database was a demanding and mandatory task for the project engineering team for two reasons: (1) differences in database designs and (2) clinicians did not consider simply discarding old data a possibility.

Between 1978 and 2007, the MOD staff at the HUVV collected information for 13,776 patients in different clinical cancer databases in various simple formats (e.g., Excel or Dbase). An external module had to be developed to discriminate and transfer the useful patient data from the previous databases to the new OIS database. A key design aspect for a successful task was minimizing the number of open text fields in the user web interface; a parser was thus implemented to

provide close fields with different options depending on its nature. This design criterion allowed automatically incorporating 94% of the patient information into the OIS database. The remaining data was thoroughly analyzed by clinicians and engineers over several months to eliminate any inconsistencies detected during the automatic transfer process.

3.2. Choosing an appropriate development technology

Several authors [12–14] suggest using suboptimal technology as a likely cause for user resistance to healthcare systems in general. As previously mentioned in Section 1, the main goal for the OIS is providing a better health service, not simply incorporating newer technologies [20]. As better and newer technology does not ensure successful OIS implementation, studying and analyzing the existing technology is mandatory in the system deployment process. Next, the relevant technological aspects that are considered important for a successful OIS deployment are described.

3.2.1. Layered web architecture

An OIS must ensure the availability of the information collected in the system [18,19] from within the hospital center, and a web environment seems a suitable platform for this purpose. ASP.NET technology was chosen as development platform because of: (i) its potential for designing user-friendly web applications, and (ii) the possibility of executing, on the server side, certain mandatory transactions to attend user requests (Javascript was also used for interactivity in the browser but not for server-side logic). As Fig. 3 depicts, ASP.NET technology is based on an N-layer architecture model with three top-level different layers: user interfaces, business logic, and data management.
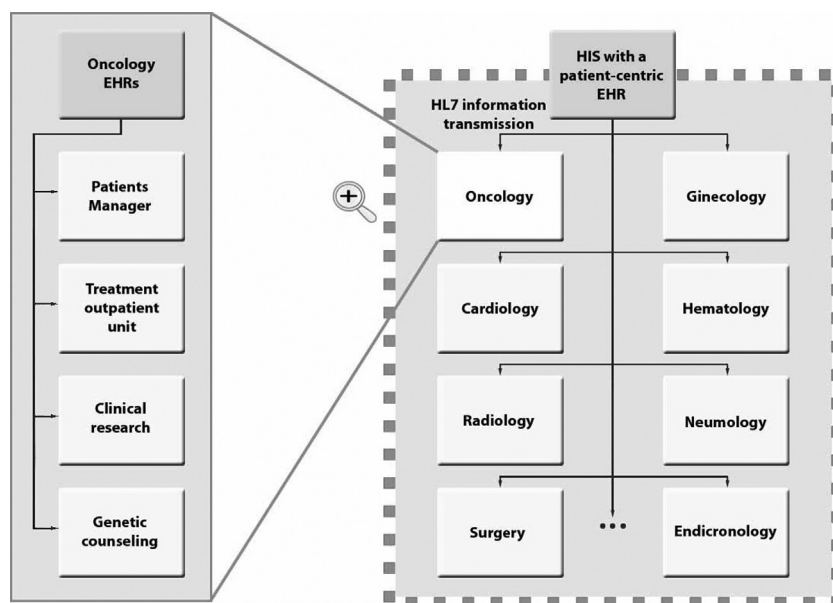
Fig. 4 – On the right, a typical hospital computing environment composed of several subsystems; on the left, the functionality of the developed OIS for the oncology computing system. Information is transmitted using the HL7 Standard.

3.2.2. Using AJAX

AJAX (Asynchronous JavaScript and XML) was used as a novel technology to improve users' experiences when interacting with the OIS. AJAX combines and exploits JavaScript and XML to send and retrieve data from a server asynchronously (in the background) without interfering with the display and behavior of the existing web page.

Using AJAX significantly increased the usability, productivity, speed and response time of the website, especially on the "heavy" web forms that displayed a large amount of data. It eliminated the start–stop–start–stop nature of traditional web pages hence allow web application to look and behave like the desktop ones, of course to a limited extent. AJAX allows pages to request small bits of information from the server instead of entire pages. For example, in our proposed OIS, AJAX only updated content in complex tables, whereas the rest of the web form remained "frozen", removing the annoying blinking effect from the client browser and a slow response to the user.

3.2.3. A standard protocol to interconnect information systems

As the literature has widely described [20,18,19,35], one fundamental basis of a HIS is the ability to communicate with other involved components, either in the same service or the rest of the hospital to perform information communication in a timely, accurate and transparent manner.

The OIS must be part of the hospital information main system (Fig. 4x), ensuring the continuity of patient care through the real-time information exchange process. The standardized Health Level 7 (HL7)[6] protocol was selected to implement bidirectional communication between the OIS and other hospital information systems.

3.2.4. Security issues

An important OIS aspect ensures information confidentiality, preventing anyone not registered with the system from accessing the information. In addition to controlling access by user credentials, the ASP.NET technology automatically addresses other usual security bugs, including SQL injection attacks [36]. Furthermore, the SHA1 algorithm is applied to encrypt and stores user credentials, and several roles are defined to restrict system functionality only to authorized users (e.g., administrator, medical oncologist, nurse, radiotherapist or data manager).

3.2.5. Controlling errors and system monitoring

Deploying the OIS into the destination service is a critical phase. It is common to find certain uncontrolled errors during the first months of the deployment phase. This drawback, coupled with the extra initial effort from physicians to adapt their working procedures, may lead to potential users rejecting the OIS.

A detailed registry of actions performed while interacting with the system is integrated into the OIS. Every OIS transaction is stored, allowing identification of the user, action type or date and time of the event. Similarly, if a change is made, the original data remain in the OIS as database backups. Therefore, this registry provides, on the one hand, the detection and recovery of uncontrolled errors during the test phase of the development process and, on the other hand, the visualization of all actions performed in the OIS by the MOD administrators.

3.2.6. System maintenance

A collaborative environment has been also used to share a maintenance document where users can report bugs and register possible suggestions to improve the OIS. This document is periodically revised by the development team, and non-critical requests are addressed every three months. The

---

6 http://www.hl7.org/.

	IN AGREEMENT		NEITHER AGREE NOR DISAGREE		DISAGREE	
	August 2010	August 2011	August 2010	August 2011	August 2010	August 2011
Access to patient information has improved with the introduction of the OIS.	13 (93%)	14 (100%)	1 (7%)	-	-	-
The use of the OIS does not increase my workload.	2 (14%)	5 (36%)	1 (7%)	3 (21%)	11 (79%)	6 (43%)
OIS implementation promotes normalization of working procedures.	9 (64%)	10 (71%)	5 (36%)	4 (29%)	-	-
Using the OIS improves the quality of care given to my patients.	8 (57%)	13 (93%)	4 (29%)	1 (7%)	2 (14%)	-
The use of an OIS hinders my relationships with patients.	9 (64%)	2 (14%)	1 (7%)	5 (36%)	4 (29%)	7 (50%)
With the OIS, it is easier to obtain updated information about the status of my patients.	14 (100%)	14 (100%)	-	-	-	-
The use of the OIS has facilitated my everyday routine work.	4 (29%)	6 (43%)	8 (57%)	6 (43%)	2 (14%)	2 (14%)

Fig. 5 – Survey results about OIS usability at three and fifteen months after its deployment.

previously described functional module division and the layered web architecture greatly facilitate the maintenance tasks, e.g., changes in visual aspect for the Patient Manager module interface imply reviewing the implementation just for this module, and only for the code related to the user-interface layer (business logic and data management layer would remain without changes). Besides, small content changes for database tables are allowed via the Database Management module.

3.3. Real-time statistical analysis

An aspect that confers additional value to the developed system is that, in addition to its capacity for collecting and managing the contained clinical cancer data, it also permits further analysis. Information systems must facilitate the measurement of several important outcomes for oncology research [23,37]. It is important not only to prospectively collect clinical information, but also to have the necessary tools to extract and manage the stored information [9,23,21]. The advantages of data collected in this way are that they represent a real-world patient cohort from which cancer incidents, therapeutic results, diagnostic procedures, prevalence of risk factors, and other information can be extracted.

A powerful filtering system was implemented containing almost all coded fields included in the OIS. Moreover, the OIS system database and statistical utilities allow evaluating results from the MOD not only in its activity and case mix but also its therapeutic efficacy. Several techniques for carrying survival analysis were implemented including the Kaplan–Meier algorithm, Cox regression and machine learning techniques based on Artificial Neural Networks (ANNs), such as Self-Organizing Maps (SOMs), Multilayer Perceptron (MLP) or C-Mantec. In particular, the latter methods, based on ANN methodologies, produced good results and have proven to be stable for survival predictions [38].

Until now, the procedure for studying a subset of patients has required (i) collecting the patient subset dataset and extracting it in a portable format, such as a text file and (ii)

off-line, importing the subset dataset into known medical commercial software, such as SPSS, to perform the study. A statistical module embedded into the OIS can thus provide clinicians with a battery of tools to be applied in real-time (on-line) for a specific patient population.

The different statistical and ANN models were implemented using MATLAB[7] or R. The Statistical Analysis module allows end users to make certain statistical studies of interest. Whenever users wish to make retrospective or prospective clinical studies, they need only to select a subset of patients in real-time from the OIS database using the filtering webpage of the Statistical Analysis module and to choose the model to be applied.

Regarding the software used to carry the statistical analysis, R proves advantageous for obtaining survival graphic images because of the graphical quality and portability of the produced images. Therefore, in addition to the advantage of creating real-time studies, physicians can directly incorporate the results into their research articles.

4. System evaluation

In the first phase of system deployment, three physicians conducted a pilot trial to check and adjust minor details of the system. After verifying OIS usability and its potential integration into the daily workflow, widespread implementation was initiated. Two training sessions were conducted, and user manuals were distributed to all staff members who were also told to contact the project managers at anytime for any type of consult.

OIS evaluation was analyzed using two different approaches. First, the percentage of medical consultations with clinical notes registered in digital formats for all medical consultations (excluding first visits) performed in the three months following the implementation of the system was qualitatively assessed; the study was again

---

[7] http://www.mathworks.es/products/matlab/index.html.

performed one year later for the same period (three months). Second, a survey was conducted to ascertain the physicians' views about the system at three and fifteen months after its implementation.

The quantitative analysis of OIS use revealed that between May and July of 2010, the OIS included clinical notes for 2719 of the 4799 total patients observed in the MOD (56%). Significantly, for the same period in 2011, clinical notes were collected in digital formats for 4704 of the 4859 consultations performed (98%).

Fourteen physicians from the MOD and the Radiation Oncology Department, all regular OIS users, responded to the survey in the initial implementation period (August 2010) and after one year (Fig. 5).[8] All users agreed that the system had greatly improved the access to information regarding the status of their patients. Although 79% of the physicians believed that using the system increased their daily workload, only 43% maintained this view one year later. Initially, slightly more than half of the users thought that the OIS had improved the quality of patient care. A year later, however, almost all users shared that opinion. Finally, while 64% of the clinicians considered that using the OIS hindered their relationships with patients, only 14% held this belief after one year.

5. Discussion and conclusions

Information and Communication Technologies (ICT) could improve safety, quality, and cost-efficiency of healthcare services by implementing the electronic health record (EHR) [6]. In this sense, the OIS includes a set of effective applications that functions as a clinical database and replaces the currently used paper procedures. Nevertheless, paper procedures were kept together with the OIS on a dual process to facilitate clinicians a progressive incorporation to the use of the OIS. The system was developed to provide a tool dedicated specifically to the practice of oncology, reflecting and improving previous work styles and procedures. Analyses and a good workflow understanding enabled us to develop a system that fits well with current clinical practices. This approach helps ensure system acceptance by its users [37,39] because a main barrier to adopting electronic medical records is difficulty in finding a system that meets such needs [10,40,41].

In addition to the OIS characteristics, other barriers may hinder its implementation. Certainly, users may be resistant to changes of this magnitude in their daily work, which can sometimes increase for those who lack basic computer skills [42]. It is important for users to become fully familiarized with the system; the training period is, therefore, crucial. This could prove difficult because in addition to the large amount of new information that the user must learn, the busy physician has little or no time for training [43]. The observed change in the use of the clinical notes functionality after only one year, from 56% to 98%, is truly remarkable. To some extent, such data are related to the evolved attitudes of physicians in the MOD toward the system, as observed in other studies [39]. It is

important to promote a positive attitude toward the system by highlighting its usefulness and potential, which can improve user acceptance and ease system adoption [44,45].

The survey results indicate the successful OIS implementation. The main explanation is most likely that improved information availability resulted in a decreased need for documentation time to obtain relevant patient information. This easy accessibility is a main determinant of the information system's efficiency [29–31]. An increase in workload is frequently reported as a limiting factor for system adoption [6]. However, as can be inferred from the evolved opinions observed in the survey, this circumstance could be related to the lack of familiarity with the system. Furthermore, users also noted the usefulness of the system in patient care, given that they can access information whenever and wherever required. The availability of prefilled templates and predetermined options in our system suggests that system use may not always imply less time for patient care. Certainly, it seems that with more OIS experience, physicians can better understand the clinical benefits offered by the system.

The OIS usability also fits well to Nielsen's definition of usability [46], which focus on five key parameters: (i) Learnability, survey results shown in Fig. 5 indicates that learning the system functionality was easy for users after a short time period; (ii) Efficiency, the use of, e.g., the clinical notes functionality raised from 56% to 98% in one year, i.e., the more advanced a user is, a higher productivity is achieved; (iii) Memorability, the similarities to previous work styles and procedures clearly allowed that learned features were not be learned again by users after an inactivity period; (iv) Errors, the OIS was designed to minimize problems of system malfunction via a detailed registry of database transactions that allows error source identification and data recovery through daily database backups; and (v) Satisfaction, survey results suggest that users' experience was satisfactory, mainly because the OIS facilitated their daily routine work, eased the access to patient information, and did not hinder their relationship with patients.

The proximity of the project management team to the end users enables feedback on the perceptions of inefficiencies and suggestions for improvement. After system implementation, we received several requests to implement and thus improve system usability. This feedback, combined with the OIS flexibility, is absolutely necessary to contribute to the system's maturity and stability [23,37].

One of the key aspects in the advancement of Oncology is clinical research, although its integration into the hard daily tasks may be really difficult. In this sense, the integration of the Clinical Research module into the OIS can help in several ways, like enhancing physicians ability to find potential candidates for clinical trials [47,34]. Moreover, the system can support physician participation by linking to clinical trials information or another basic science research tools. Finally, the quick access to clinical data facilitates the completion of Case Report Forms. Consequently, the use of a Clinical Research module into an OIS is likely to become the standard [23].

The use of standardized clinical contents is also crucial to unify diagnosis and treatment criteria, and report clinical activity to the administration authorities. The

---

[8] This survey data sample size was too small for anything other than basic descriptive statistics.

International Statistical Classification of Diseases and Related Health Problems (ICD-9) [32] was then used to classify neoplasms, treatment administration, toxicities and other procedures. TNM tumor staging was also used to specify the extent of the tumor (T), the extent of spread to the lymph nodes (N), and the presence of distant metastasis (M).

It is important to outline that there was not a commercial purpose in the OIS development, so aspects as development time and costs were not critical factors in the planning tasks. The main purpose in developing the OIS was to provide different utilities that reflect the working methodology of the original paper-based records as closely as possible, what is difficult to achieve by a commercial software application. The ultimate goal of the OIS was to systematize and unify the daily work of the entire cancer care unit for the MOD at HUVV. In addition, the OIS has been developed in the framework of a project financed in part by public funds with the additional goal of transferring the results of research in computational survival analysis to the Public Health System.

In this article, authors provide the application of different existing approaches to solve critical issues appearing in recent literature as hindrances that avoid the successful deployment and usability of a HIS. The addressing of these deficiencies allow reaching the HIS goal: improve and achieve not only better technology but also better medicine.

In conclusion, developing an information system requires a thorough prior analysis of clinical activities and their workflows, as well as considering the specific needs of future users, combined with the use of the adequate technology. An information system for an oncology department must include all activities that occur daily, which are related not only to patient care but also to clinical research and, in the near future, to basic research. The proximity of the project management team, especially during the early implementation phase, helps guarantee the integration of an information system for clinical practice.

Authors' contributions

DU, NR, JLS, LF, EA and JMJ contributed to the conception and design of the study. DU, JLS, NR and JMJ were responsible for the analysis, design and implementation of the OIS. NR and EA contributed to the collection and evaluation of the data. DU, NR, LF and JMJ contributed to the drafting of the manuscript. All authors approved the manuscript.

Conflict of interest

The authors declare that they have no conflicts of interest relating to the publication of this manuscript.

Acknowledgements

Summary points

Known before the study:

- Electronic health records (EHRs) improve the quality of care, diminishes dangerous medical errors and helps control costs (see Refs. [4,8,13]).
- Applying health information technology to patient health data recording is not as widespread as one may expect, despite its capacity to improve the efficiency and effectiveness of health care (see Refs. [8,13,16,36]).
- Sub optimal technology and potential user resistance (see Refs. [25,27,29]), the lack of integration of requirements, interfaces and procedures into routine clinical practices (see Refs. [9,35,37]), insufficient information transmission among different health information systems (HISs) (see Refs. [18,24]), and the absence of User-Centered Design approaches in the systems' development (see Ref. [20]) are critical issues associated with insufficient EHR use.
- In the oncology field, the American Society of Clinical Oncology (ASCO) has recently recognized the essential role of EHRs in advancing the quality of care for oncologic patients (see Refs. [6,17,30,42]), seeking to practice personalized medicine and fulfill prospective/retrospective real-time clinical research studies.

What the study has added to the body of knowledge:

- It reports an experience in the design and implementation of a User-Centered Design for an Oncology Information System (OIS), as a specific HIS software, focusing on aspects mentioned by practitioners to make the system more user-friendly and useful in their daily tasks.
- It provides design and implementation solutions to known critical issues associated with insufficient EHR use that are recently described in the literature (see Sections 3.1 and 3.2).
- Following ASCO guideline, the integration of an embedded statistical tool is described. This module allows the clinicians to perform survival analysis in real time, freeing them from the arduous tasks of selecting the patients to be included in a clinical research study and exporting the data to a survival analysis software package, similar to SPSS, R, or STATA (see Section 3.3).
- The percentage of electronic clinical records (over the total patients observed) grew up from 56% to 98% in one year (see Fig. 5), what demonstrates the system usability. Only the 43% of the physicians believed that using the OIS increased their daily workload (from the initial 79%).
- To date, almost all users think that the OIS has improved the quality of patient care and their relationships with patients (see Section 4).

Appendix A. Glossary of acronyms

AJAX	Asynchronous JavaScript and XML
ANN	Artificial Neural Networks
ASCO	American Society of Clinical Oncology
CORE	Clinical Oncology Requirements for the EHR
EHR	Electronic Health Record
HIS	Health Information System
HL7	Health Level 7
HUVV	Hospital Universitario Virgen de la Victoria
ICT	Information and Communication Technologies
OIS	Oncology Information System
MOD	Medical Oncology Department
MLP	Multilayer Perceptron
SOMs	Self-Organizing Maps
SRS	Software Requirements Specification
UCD	User-Centered Design

REFERENCES

[1] R.J. Bleicher, J.R. Beck, Cancer: Principles & Practice of Oncology, vol. 2, Lippincott Williams & Wilkins, Philadelphia, USA, 2007.

[2] G.F. Murphy, M.A. Hanken, K.A. Waters, Electronic Health Records: Changing the Vision, Saunders, Philadelphia, USA, 1999.

[3] D.W. Bates, A.A. Gawande, Improving safety with information technology, N. Engl. J. Med. 348 (2003) 2526–2534.

[4] B. Chaudhry, J. Wang, S. Wu, M. Maglione, W. Mojica, E. Roth, S.C. Morton, P.G. Shekelle, Systematic review: impact of health information technology on quality, efficiency, and costs of medical care, Ann. Intern. Med. 144 (2006) 742–752.

[5] R. Amarasingham, L. Plantinga, M. Diener-West, D.J. Gaskin, N.R. Powe, Clinical information technologies and inpatient outcomes: a multiple hospital study, Arch. Intern. Med. 169 (2009) 108–114.

[6] M. Gagnon, M. Ouimet, G. Godin, M. Rousseau, M. Labrecque, Y. Leduc, A. Ben Abdeljelil, Multi-level analysis of electronic health record adoption by health care professionals: a study protocol, Implement. Sci. 5 (2010).

[7] P.G. Shekelle, S.C. Morton, E.B. Keeler, Costs and benefits of health information technology, Evid. Rep./Technol. Assess. (2006) 1–71.

[8] J. Hendy, N. Fulop, B.C. Reeves, A. Hutchings, S. Collin, Implementing the NHS information technology programme: qualitative study of progress in acute trusts, BMJ 334 (2007) 1360+.

[9] A.K. Jha, Meaningful use of electronic health records: the road ahead, J. Am. Med. Assoc. 304 (2010) 1709–1710.

[10] C.M. DesRoches, E.G. Campbell, S.R. Rao, K. Donelan, T.G. Ferris, A. Jha, R. Kaushal, D.E. Levy, S. Rosenbaum, A.E. Shields, et al., Electronic health records in ambulatory care – a national survey of physicians, N. Engl. J. Med. 359 (2008) 50–60.

[11] D. Protti, Comparison of information technology in general practice in 10 countries, Healthcare Quart. 10 (2007) 107–116.

[12] G.A. Loomis, J.S. Ries, R.M. Saywell, N.R. Thakker, If electronic medical records are so great, why aren't family physicians using them? J. Fam. Pract. 51 (2002) 636–641.

[13] G. Makoul, R.H. Curry, P.C. Tang, The use of electronic medical records: communication patterns in outpatient encounters, J. Am. Med. Inform. Assoc. 8 (2001) 610–615.

[14] R.H. Miller, I. Sim, Physicians' use of electronic medical records: barriers and solutions, Health Aff. (Project Hope) 23 (2004) 116–126.

[15] M.C. Beuscart-Zephir, F. Anceaux, V. Crinquette, J.M. Renard, Integrating users' activity modeling in the design and assessment of hospital electronic patient records: the example of anesthesia, Int. J. Med. Inf. 64 (2001) 157–171.

[16] P. Staccini, Modelling health care processes for eliciting user requirements: a way to link a quality paradigm and clinical information system design, Int. J. Med. Inf. 64 (2001) 129–142.

[17] B. Rahimi, V. Vimarlund, T. Timpka, Health information system implementation: a qualitative meta-analysis, J. Med. Syst. 33 (2009) 359–368.

[18] N. Liu, J. Li, Design and implementation of embedded medical data transmission platform based on HL7/XML system, J. Converg. Inform. Technol. 6 (2008) 274–280.

[19] M. Hamid, H. Azamossadat, A. Farkhondeh, G. Raheleh, Infrastructures of the system for developing electronic health record, J. Paramed. Sci. 2 (2011) 48–55.

[20] B.W. Hesse, C. Hanna, H.A. Massett, N.K. Hesse, Outside the box: will information technology be a viable intervention to improve the quality of cancer care? J. Natl. Cancer Inst. Monogr. 2010 (2010) 81–89.

[21] D. Whippen, M.J. Deering, E.P. Ambinder, Advancing high-quality cancer care, J. Oncol. Pract. 3 (2007) 208–211.

[22] American Society of Clinical Oncology, The Oncology Health Record Field Guide: Selecting and Implementing an EHR, ASCO, Alexandria, VA, 2008.

[23] J. Goldwein, Using an electronic health record for research, J. Oncol. Pract. 3 (2007) 278–279.

[24] R.S. Miller, Electronic health records for the practicing oncologist: 2007 update on ASCO's role, J. Oncol. Pract. 3 (2007) 106–107.

[25] T.E. Wolfe, Making the case for electronic health records: a report from ASCO's EHR symposium, J. Oncol. Pract. 4 (2008) 41–42.

[26] American Society of Clinical Oncology (ASCO), Clinical Oncology Requirements for the EHR (CORE), 2009.

[27] J.-Y. Mao, K. Vredenburg, P.W. Smith, T. Carey, The state of user-centered design practice, Commun. ACM 48 (2005) 105–109.

[28] K. Vredenburg, J.Y. Mao, P.W. Smith, T. Carey, A survey of user-centered design practice, in: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems: Changing our World, Changing Ourselves, CHI '02, ACM, 2002, pp. 471–478.

[29] J. Allan, J. Englebright, Patient-centered documentation: an effective and efficient use of clinical information systems, J. Nurs. Adm. 30 (2000) 90–95.

[30] P. Yu, S. Gandhidasan, A.A. Miller, Different usage of the same oncology information system in two hospitals in Sydney – lessons go beyond the initial introduction, Int. J. Med. Inf. 79 (2010) 422–429.

[31] M.M. Yusof, L. Stergioulas, J. Zugic, Health information systems adoption: findings from a systematic review, Stud. Health Technol. Inform. 129 (2007) 262–266.

[32] CDC, ICD-9-CM Official Guidelines for Coding and Reporting, http://www.eicd.com/Guidelines/Default.htm, 2007.

[33] A. Trotti, A.D. Colevas, A. Setser, V. Rusch, D. Jaques, V. Budach, C. Langer, B. Murphy, R. Cumberlin, C.N. Coleman, P. Rubin, Ctcae v3.0: development of a comprehensive grading system for the adverse effects of cancer treatment, Semin. Radiat. Oncol. 13 (2003) 176–181.

[34] M. Dugas, M. Lange, W.E. Berdel, C. Muller-Tidow, Workflow to improve patient recruitment for clinical trials within hospital information systems – a case-study, Trials 9 (2008) 2+.

[35] Y.-H. Lu, C.-C. Kuo, Y.-B. Huang, Webbio, a web-based management and analysis system for patient data of biological products in hospital, J. Med. Syst. 35 (2011) 579–584.

[36] C. Alonso, D. Kachakil, R. Bordón, A. Guzmán, M. Beltrán, Time-based Blind Injection using Heavy Queries, http://www.defcon.org/images/defcon-16/dc16-presentations/alonso-parada/defcon-16-alonso-parada-wp.pdf, 2005.

[37] E.P. Ambinder, Electronic health records, J. Oncol. Pract. 1 (2005) 57–63.

[38] J.M. Jerez, L. Franco, E. Alba, A. Llombart-Cussac, A. Lluch, N. Ribelles, B. Munárriz, M. Martín, Improvement of breast cancer relapse prediction in high risk intervals using artificial neural networks, Breast Cancer Res. Treat. 94 (2005) 265–272.

[39] V. Castillo, A. Martinez-Garcia, J. Pulido, A knowledge-based taxonomy of critical factors for adopting electronic health record systems by physicians: a systematic literature review, BMC Med. Inform. Decis. Making 10 (2010) 60.

[40] J.A. Linder, J.L. Schnipper, R. Tsurikova, A.J. Melnikas, L.A. Volk, B. Middleton, Barriers to electronic health record use during patient visits, in: AMIA Annual Symposium Proceedings, 2006, pp. 499–503.

[41] M.H. Trivedi, E.J. Daly, J.K. Kern, B.D. Grannemann, P. Sunderajan, C.A. Claassen, Barriers to implementation of a computerized decision support system for depression: an observational report on lessons learned in "real world" clinical settings, BMC Med. Inform. Decis. Making 9 (2009).

[42] P. Yu, D. Hailey, H. Li, Caregivers' acceptance of electronic documentation in nursing homes, J. Telemed. Telecare 14 (2008) 261–265.

[43] M. Puffer, J. Ferguson, B. Wright, J. Osborn, A. Anshus, B. Cahill, J. Kamath, M. Ryan, Partnering with clinical providers to enhance the efficiency of an EMR, J. Healthcare Inf. Manag. 21 (2007) 24–32.

[44] L.E. Penrod, C.S. Gadd, Attitudes of academic-based and community-based physicians regarding EMR use during outpatient encounters, in: Proceedings AMIA Annual Symposium, 2001, pp. 528–532.

[45] J. Aarts, H. Doorewaard, M. Berg, Understanding implementation: the case of a computerized physician order entry system in a large Dutch university medical center, J. Am. Med. Inform. Assoc. 11 (2004) 207–216.

[46] J. Nielsen, Usability engineering, Morgan Kaufmann Publishers, San Francisco, CA, 1994.

[47] P.J. Wallace, Reshaping cancer learning through the use of health information technology, Health Aff. (Millwood) 26 (2007) w169–w177.