Support of Daily ECG Procedures in a Cardiology Department via the Integration of an Existing Clinical Database and a Commercial ECG Management System

Franco Chiarugi, Dott. Ing.,* David Lombardi, Dott.,† Philip J. Lees,*
Catherine E. Chronaki, M.Sc.,* Manolis Tsiknakis, Ph.D.,*
and Stelios C. Orphanoudakis, Ph.D.**

From the *Center of Medical Informatics and Health Telematics Applications (CMI-HTA),
Institute of Computer Science (ICS), Foundation for Research and Technology—Hellas (FORTH),
Heraklion, Crete, Greece; †R&D Dept., Mortara Instrument Inc., Milwaukee, Wisconsin, USA;
**Department of Computer Science, University of Crete, Heraklion, Crete, Greece

Background: In the context of HYGEIAnet, the regional health telematics network of Crete, a clinical cardiology database (CARDIS) has been installed in several hospitals. The large number of resting ECGs recorded daily made it a priority to have computerized support for the entire ECG procedure.

Methods: Starting in late 2000, ICS-FORTH and Mortara Instrument, Inc., collaborated to integrate the Mortara E-Scribe/NT ECG management system with CARDIS in order to support daily ECG procedures. CARDIS was extended to allow automatic ordering of daily ECGs via E-Scribe/NT. The ECG order list is downloaded to the electrocardiographs and executed, the recorded ECGs are transmitted to E-Scribe/NT, where confirmed ECG records are linked back to CARDIS. A thorough testing period was used to identify and correct problems. An ECG viewer/printer was extended to read ECG files in E-Scribe/NT format.

Results: The integration of E-Scribe/NT and CARDIS, enabling automatic scheduling of ECG orders and immediate availability of confirmed ECGs records for viewing and printing in the clinical database, took approximately 4 man months. The performance of the system is highly satisfactory and it is now ready for deployment in the hospital.

Conclusions: Integration of a commercially available ECG management system with an existing clinical database can provide a rapid, practical solution that requires no major modifications to either software component. The success of this project makes us optimistic about extending CARDIS to support additional examination procedures such as digital coronary angiography and ultrasound examinations.

A.N.E. 2002;7(3):263–270

medical records systems; resting ECG; ECG management systems; databases;
workflow management; procedure automation

With the aid of modern computer systems the archiving of resting ECG recordings in digital form can provide more rapid and convenient access to this valuable diagnostic tool. ECG management

systems are currently available from a number of electrocardiograph manufacturers and offer facilities such as editing of ECG diagnosis using configurable acronyms, serial comparison of multiple

Grants: The work reported in this paper was supported in part by the PICNIC project (IST-1999-10345) and the project "Crete—a telematics center" funded by the INTERREG II program.

Address for reprints: Franco Chiarugi, CMI-HTA, Institute of Computer Science, FORTH, Science and Technology Park of Crete, P.O. Box 1385, GR 711 10 Heraklion, Crete, Greece. Fax: +30 (81) 391601; E-mail: chiarugi@ics.forth.gr

ECGs from the same patient, as well as direct communication with the electrocardiograph devices.

However, such commercial systems generally use their own proprietary database structure, and typically operate on a 'stand alone' basis. Clearly, cardiologists working in departments that already have a clinical database would prefer to be able to access ECG records directly, as part of the patient's electronic record, rather than having to switch between two separate systems in order to obtain a complete clinical picture.

Here we report on our project to integrate a commercially available digital ECG management system with an existing clinical cardiology database in order to provide a unified view of a patient's medical history, including digitally stored ECG records. We also take the opportunity to review the developing role of computers in electrocardiology, in light of the progression of medical data archiving from a local to a regional, national, or even international scope using network and Internet technologies.

Context

During the development of HYGEIAnet, the regional health telematics network of Crete,^{1,2} a clinical cardiology database (CARDIS) was installed in several hospitals in different parts of the island. CARDIS maintains a comprehensive archive of patient demographic and clinical data including diagnostic examinations.

However, CARDIS does not currently provide direct access to vital signs and digital images acquired by various medical devices. These are managed by separate systems and their results are summarized in text and entered manually as a part of the admission record. Such data entry requires an appreciable amount of time, especially when the number of examinations is high, and this is one of the main obstacles to the daily use of the system.

In view of the large number of routine resting ECGs recorded daily in a large cardiology department, ICS-FORTH decided that it would be beneficial to add digital ECG records to the set of data accessible via CARDIS.³ Rather than create such a system from scratch, which would require a great deal of time and effort, the possibility was investigated of using commercially available ECG management software and integrating it with the CARDIS clinical database.

Within the regional health network, electrocardiographs from different manufacturers are used, so standards for ECG storage and data exchange with ECG devices were considered. The only existing standard is the Standard Communication Protocol for ECG devices (SCP-ECG).^{4,5} Unfortunately, this standard has not been implemented by most manufacturers. Furthermore, it allows so much flexibility in its implementation that defining precisely what is a standard ECG format can be very difficult.⁶ In view of this, the use of SCP-ECG was not considered essential at the present time.

Thus, the main requirements for support of daily ECG procedures by the integrated system were:

- Automation of examination ordering with automatic downloading of patient data to the electrocardiograph (to avoid needless data re-entry on the medical device side and the potential errors that would entail).
- Use of existing dedicated tools for examination confirmation and reporting.
- Automated archiving of confirmed examination results.
- Graphical display/printout of clinical examinations from the clinical database.

The ultimate goal of such integration was to give to the end-user the impression of a uniform seamless system, where every piece of information can be easily accessed and reviewed, regardless of storage location and format.

This requirement drove the design of the integration more than any other described so far. In particular, it implied that technical solutions would have to be provided to achieve the necessary consistency between the CARDIS database and the ECG management system database, despite the fact that CARDIS and the ECG management system would have their own independent database structures.

An additional issue arising from the locale was that CARDIS patients' demographic data are stored in the Greek language, which uses a character set not generally supported by standalone electrocardiographs.

With the above ends in view, after some investigation of commercially available ECG management systems ICS-FORTH settled on the E-Scribe/NT package (Mortara Instrument, Inc., Milwaukee, WI, USA). The choice was based not only on the desired technical features (Table 1), but

Table 1. Features of the E-Scribe/NT ECG Management System

-
1. Connection with multiple electrocardiographs for sending orders and receiving ECGs
 2. Graphical ECG display and printout
 3. Possibility of ECG serial comparison
 4. Tools such as zoom and caliper for a detailed view of the ECG signal
 5. Possibility to produce activity reports
 6. ECG storage and confirmation
 7. ECG editing with configurable acronyms for diagnosis entry
-

also on the manufacturer's willingness to cooperate closely on the project: such close cooperation was deemed essential.

METHODS

In late 2000 we started a joint project for the design and the implementation of the interface between CARDIS and E-Scribe/NT.

Efforts were made to identify the main ECG procedures currently followed in the hospital departments and to model them, trying to minimize the user interaction with the computer systems and to avoid duplication of medical staff activities.

Resting ECG Workflow

The automation of daily procedures as regards the ordering, recording, and diagnosis of resting ECGs for in-patients can be modeled according to the following main workflow:

- (a) Automatic transmission of daily ECG orders for all in-patients from CARDIS to the ECG management system;
- (b) Downloading of the ECG orders from the ECG management system to the electrocardiographs;
- (c) Recording of ECGs by the technician, according to the received order list, and their transmission to the ECG management system;
- (d) Editing the ECG diagnostic proposal and confirmation of the diagnosis by the cardiologist;
- (e) Automatic linking of confirmed ECGs to the patient's electronic record.

Auxiliary workflows include emergency ECGs for patients who are not in the cardiology informa-

tion system, emergency ECGs for in-patients, and recording of any unscheduled ECGs. However, the main workflow is expected to amount for about 80–90% of cases. Other procedures involve correction of data entry errors that require manual intervention.

Implementation of the ECG Workflow

The implementation of the workflow posed challenges due to the lack of well-established standards in ECG ordering and localization issues. However, these were overcome with the aid of close cooperation between ICS-FORTH and the Mortara R&D department.

It was decided that the master copy of the patient demographics would be the one stored in the CARDIS database, since the routine ECG workflow starts with the admission of the patient to the cardiology department. This decision was important for situations where human errors and/or exceptional workflows might misalign the two systems.

Additional complications were introduced by the fact that the ECG carts did not support the Greek alphabet. The ECG management workstation accepted the orders correctly, but could not forward them to the electrocardiograph in intelligible form. It was thus necessary to employ a transliteration algorithm. Routine ECG orders for all patients currently in the clinic are transferred to the ECG management system using a scheduled procedure. Upon receipt, all patient demographics are automatically transliterated into the Latin alphabet before the order is transmitted to the electrocardiograph.

The advantage of this approach is that the technician or nurse whose job it is to record routine ECGs no longer has to enter any data on the device, since the patients' names are already listed (as well as items such as age and sex that help the electrocardiograph's interpretation program achieve a more accurate diagnostic proposal). The technician simply selects a patient from the list, and saves the ECG when recording is completed. All ECGs recorded may be transferred to the ECG management system in a single operation that typically takes a few seconds per ECG. The successfully transmitted ECGs are automatically deleted from the local memory of the electrocardiograph.

When the ECGs arrive in the management system, the original demographics for each patient are

Figure 1. The UniPro ECG viewer.

Figure 1. The UniPro ECG viewer.

recovered automatically from CARDIS in Greek, using the patient's unique identity code, and written to the ECG record before its storage in the ECG management database. During this procedure, the demographics data on the ECG management side are double-checked against the data stored in CARDIS and any problems are noted for manual intervention.

In this way, the doctor confirming the ECG is able to view all the relevant data in the local language. The doctors edit and confirm the diagnosis for all the received ECGs (working with E-Scribe/NT), using configurable acronyms and additional tools such as zoom and serial comparison. Among the records that need to be edited and confirmed, those that have been flagged for mismatch can easily be identified. The ECG confirmation automatically links the ECGs to CARDIS and the diagnosis or the whole ECG can be viewed from CARDIS with a specific ECG viewer built by ICS-FORTH as an extension of its SCP-ECG viewer (Fig. 1). The link to the CARDIS database is established only if and when any mismatches are solved. Should this not be the case, the record confirmation status is cleared and the record itself is flagged for mismatch review. This ensures that only correct ECGs are linked to CARDIS.

Figure 2 shows the functional schema of the integrated system.

Testing

Before the introduction of an automated workflow to a hospital environment, intensive testing under realistic situations was considered necessary, so as to minimize the risk of loss or corruption of real clinical data. For this purpose, special testing software was developed to simulate patient traffic in a typical cardiology department.⁷ The integrated system was tested using a pool of 1000 fictitious patients over a 3-month period, mimicking daily ECG recording and archiving activity (Table 2).

RESULTS

The work required for the technical modifications and testing came to a total of approximately 4 man months.

A number of problems were identified with the integrated system and were corrected. The main adjustments involved the elimination of a few flaws in the overall workflow with a view to the optimization and minimization of the work re-

Figure 2. Functional diagram of CARDIS—E-Scribe/NT integration.

quired from the users of the system. For example, the electrocardiograph software was modified to simplify and facilitate the association of the ac-

Table 2. Testing Procedure Using Custom Software to Simulate Patient Traffic

Initialize Simulator and Synchronize Databases

1. Advance simulator to next 'day'
 2. Download ECG orders to electrocardiograph
 3. Record ECGs using ECG simulator device
 4. Upload ECGs to E-Scribe/NT
 5. Confirm ECG records and store in archive
 6. Open patient roster for day
 7. Check access to digital ECGs from CARDIS
- Repeat steps 1–7

Steps 2–4 would normally be performed by a nurse or medical technician, Step 5 by a cardiologist.

quired ECG with a patient included in the downloaded order list and new components were added to CARDIS for the easy selection and display of stored ECG records.

By the end of the test phase, the performance of the system was highly satisfactory and it is now ready for deployment in the hospital.

DISCUSSION

Digital storage of medical examinations is the first step in the move towards a multimedia electronic patient record, where all the information can be displayed and made available to a doctor in a structured and user-friendly way that cannot be achieved with the traditional use of examination printout reports on paper.^{8–10} In this digital era, the current trend worldwide is towards the replace-

ment of analog medical devices with digital ones and the conversion of examinations stored in analog form to a digital form.¹¹

On the other hand, the evident benefits of digital ECGs, computerized ECGs, and ECG databases may be offset by the potential extra work required in a department in order to implement new electrocardiographs and procedures for computerized ECG reporting and storage. Given the pressures under which medical professionals often carry out their daily activities, it must be accepted that unless computerization makes their work more easy and productive, allowing for a short learning cycle, they are likely to reject it. The best way to overcome this initial friction is to try to optimize the whole workflow so that daily ECG activities can be performed in less time compared with the previously existing procedures.

The above consideration was paramount in the design of the integrated system described here. Avoiding the manual re-entering of information at different points was a major step towards improving efficiency, as well as the consistency of clinical data. The ability to select a patient from a list that is already present on the electrocardiograph, rather than typing in information using what is often a clumsy keyboard, represents a clear saving in time, compared to which the time required for downloading the order and returning the recorded ECGs to the management system is negligible. Although the confirmation of ECGs through E-Scribe/NT prior to archiving may seem to be a chore at first, this is counterbalanced by the easy availability of those recordings at a later date, for further analysis or comparison.

In the integrated system physicians may review cardiology patient history and ECG examinations in their graphical form, either through the native CARDIS interface, or through a specially designed Web interface.^{12,13} This enables authorized doctors to access the patient's clinical information at any time from anywhere in the context of the regional network.

The integration of the two systems is seamless and transparent, which means that it is unnecessary for the user to understand, or even be aware of the communication between them. ECGs stored in the archive may be viewed simply and routinely just as another part of the patient's electronic medical record, while the more sophisticated capabilities of the ECG management system are available for those who need them. Technicians and nursing

staff may use the ECG management workstation to modify pending orders, manually schedule new orders when necessary, fill out missing information and correct errors, while cardiologists use the same system to confirm the recorded ECGs.

The deployment of any new technology has to follow a series of steps. It may be necessary to upgrade an existing installation with new functionalities without losing any data collected with the previous version of the system. In such cases, particular attention must be paid to the testing phase and a simulated working environment can help to achieve this end. Computer-based simulators have been used extensively for medical training,¹⁴⁻²⁰ but simulations of the administrative processes and workflows in a cardiology department are few and far between.²¹ The patient traffic simulator we developed allowed us to test and debug the system thoroughly before its installation in a real clinical setting. It has also proved useful for demonstrating the system and as a training aid for medical technicians and cardiologists, to help familiarize them with the operation of the hardware and software before its use in everyday practice.

The Role of the Computer in Electrocardiology

In 1988 Boineau²² proposed a diagram, recently reviewed by Titomir,²³ to describe the development of modern electrocardiography starting from the end of the nineteenth century. According to that diagram, the history of electrocardiology is divided into "Ancient History" and the "Modern Era." Ancient History refers to the period of formation of electrocardiography, leading to its introduction as a commonly accepted diagnostic technique.

The beginning of the Modern Era was in 1957, when a New York Academy of Sciences symposium and its proceedings had a decisive impact on the evolution of electrocardiology. Since that time electrocardiology has inevitably been influenced by the development of modern computers. Indeed, computer interpretation of the ECG was one of the first applications of computers in health care.

The first attempt to automate ECG analysis using a digital computer was made as early as 1957 by Pipberger et al.²⁴ and other attempts soon followed.²⁵ In the 1970s and 1980s, computer processing of ECGs increased rapidly²⁶ and shifted from university to industry and to commercial ECG devices. By 1990 more than 100 million ECGs per

annum were being interpreted by a computerized program.²⁷ In parallel with the evolution of computer technology, electrocardiographs evolved from analog recorders to devices with the ability to store an ECG locally in digital format. Fifteen years ago, transmission of ECGs was mainly performed using analog techniques, but during the last 10 years almost all newly developed electrocardiographs with medium or high capabilities offer features for digital recording and interpretation and the possibility to transfer a digitally stored ECG to a data management system.

Digital ECGs allow the application of various computerized algorithms to the ECGs, not only interpretation programs, and in recent years new diagnostic techniques have been applied, such as RR variability, late potential analysis, and QT dispersion analysis. Moreover, the collection of digital ECGs in a data management system can allow their access through the World Wide Web,²⁸ their easy sharing for secondary consultation, or to assure the continuity of care of the patient, and further capabilities, such as comparison with previous ECGs of the same patient or with similar ECGs from a reference database.

Current Developments

Regional networks and efforts directed towards achieving an integrated electronic health record presuppose the integration of ECG devices with clinical databases and the availability of digital ECG records. Nowadays, the main obstacle is that the most electrocardiographs are still custom designed, without a standard operating system, and they cannot support the HL7 standard²⁹ for communication through a computer network. Future generations of electrocardiographs, PC-based or palm-top based with a standard operating system, could solve this problem, allowing the easy support of HL7 on the ECG devices. Given that the only existing standard, the SCP-ECG protocol, has still not been implemented by most main manufacturers, the need for a custom solution is nowadays almost inevitable. However, the wider use of SCP-ECG in the future, with main functions that are truly standardized, could allow the extension of the project described here to a multi-vendor solution, capable of working without a manufacturer-specific ECG management system and interacting with electrocardiographs from different manufacturers using the popular 'plug and play' model.

CONCLUSIONS

Integration of a commercially available ECG management system with an existing clinical information system provides a rapid (about 4 months manpower), practical solution that does not require major modifications to either software component.

The success of this project makes us optimistic about extending CARDIS to support additional examination procedures such as digital coronary angiography and ultrasound examinations.

REFERENCES

1. <http://www.hygeianet.gr>.
2. Katehakis D, Lelis P, Karabela E, et al. An environment for the creation of an integrated electronic health record in HYGEIANet, the regional health telematics network of Crete. TEPR 2000, Your Connection to Electronic Healthcare, San Francisco, CA, 2000;1:89-98.
3. Chiarugi F, Lombardi D, Lees PJ, et al. Integration of an ECG management system with an existing clinical database to support daily ECG procedures in a cardiology department. Proceedings of the XXIIIrd. Congress of the European Society of Cardiology, September 1-5, 2001, Stockholm, Sweden (computer demonstration, abstract A2101).
4. Standard Communication Protocol for Computer-Assisted Electrocardiography, Version 1.0, CEN—Comité Européen de Normalization, 1993.
5. Proposal for ISO Standard based on CEN prENV 1064.00 "Standard Communications Protocol for Computer-Assisted Electrocardiography" with modifications proposed by AAMI SCP-ECG Working Group, Revision 1.3, Draft, AAMI—Association for the Advancement of Medical Instrumentation, 1999.
6. Chiarugi F, Lees PJ, Chronaki CE, et al. Developing manufacturer-independent components for ECG viewing and data exchange with ECG devices: Can the SCP-ECG standard help? Comput Cardiol 2001;28:185-188.
7. Lees PJ, Chiarugi F, Lombardi D, et al. Simulator of patient traffic in a cardiology department for testing the integration of an ECG management system with an existing clinical database. Comput Cardiol 2001;28:197-200.
8. Dayhoff RE, Kuzmak PM, Kirin G, et al. Providing a complete online multimedia patient record. Proc AMIA Symp 1999;241-245.
9. Cornet R, van Mulligen EM, Timmers T. A cooperative model for integration in a cardiology outpatient clinic. Proc Annu Symp Comput Appl Med Care 1994;590-594.
10. van der Putten N, Nelwan S, Meij S, et al. Patient 98: A component-based multimedia workstation for cardiac care and research. Comput Cardiol 1999;26:77-80.
11. Ehler D, Vacek JL, Bansal S, et al. Transition to an all-digital echocardiography laboratory: A large, multi-site private cardiology practice experience. J Am Soc Echocardiogr 2000;13:1109-1116.
12. Lees PJ, Chronaki CE, Simantirakis EN, et al. Remote access to medical records via the Internet: Is it feasible? Proceedings of the XXIst Congress of the European Society of Cardiology, August 28-September 1, 1999, Barcelona, Spain (abstract).
13. Lees PJ, Chronaki CE, Simantirakis EN, et al. Remote access to medical records via the Internet: Feasibility, security, and multilingual considerations. Comput Cardiol 1999;26:89-92.

14. Issenberg SB, McGaghie WC, Hart IR, et al. Simulation technology for health care professional skills training and assessment. *JAMA* 1999;282:861-866.
15. Issenberg SB, Gordon MS, Gordon DL, et al. Simulation and new learning technologies. *Med Teach* 2001;23:16-23.
16. St Clair EW, Oddone EZ, Waugh RA, et al. Assessing house-staff diagnostic skills using a cardiology patient simulator. *Ann Intern Med* 1992;117:751-756.
17. Jones JS, Hunt SJ, Carlson SA, et al. Assessing bedside cardiologic examination skills using "Harvey," a cardiology patient simulator. *Acad Emerg Med* 1997;4:980-985.
18. Dawson SL, Cotin S, Meglan D, et al. Designing a computer-based simulator for interventional cardiology training. *Catheter Cardiovasc Interv* 2000;51:522-527.
19. Wang Y, Chui C, Lim H, et al. Real-time interactive simulator for percutaneous coronary revascularization procedures. *Comput Aided Surg* 1998;3:211-227.
20. Farahifar D, Cassot F, Bodard H, et al. Velocity profiles in the wake of two prosthetic heart valves using a new cardiovascular simulator. *J Biomech* 1985;18:789-802.
21. Shimatonis KG. Imitative model of the operation of medical institutions and its use in the modeling of an ambulatory cardiologic service. *Med Tekh* 1983;5:8-11.
22. Boineau JP. Electrocardiology: A 30-year perspective. *Ah serendipity, my fulsome friend.* *J Electrocardiol* 1988;21 Suppl:S1-9.
23. Titomir LI. The remote past and near future of electrocardiology: Viewpoint of a biomedical engineer. *Bratisl Lek Listy* 2000;101:272-279.
24. Pipberger HV, Arms RJ, Stallman FW. Automatic screening of normal and abnormal electrocardiograms by means of a digital electronic computer. *Proc Soc Exp Biol Med* 1961;106:130-132.
25. Caceres CA, Steinberg CA, Abraham S, et al. Computer extraction of electrocardiographic parameters. *Circulation* 1962;25:356-362.
26. Willems JL, Arnaud P, van Bommel JH, et al. Common standards for quantitative electrocardiography: Goals and main results. CSE Working Party. *Methods Inf Med* 1990;29:263-271.
27. MacFarlane PW. A brief history of computer-assisted electrocardiography. *Methods Inf Med* 1990;29:272-281.
28. Ashley EA, Raxwal V, Froelicher V. An evidence-based review of the resting electrocardiogram as a screening technique for heart disease. *Prog Cardiovasc Dis* 2001;44:55-67.
29. "HL7: Health Level 7." <http://www.hl7.org>.