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Optimizing the Interventional Cardiology Facility: Services Integration in Routine Workflow

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Summary

Objectives: Integration of administrative and clinical data, imaging, and expert services, although challenging, is a key requirement in contemporary interventional cardiology facilities (ICF). We propose a workflow-oriented hybrid system to support the ICF and investigate its feasibility and effectiveness in a referral medical center.

Methods: We have developed a Java-powered hybrid system (NetCARDIO), able to support over web synchronous and asynchronous data management, real-time multimedia data telemonitoring and continuous telementoring. Data regarding procedural rates, treatment planning and radiation exposure were collected over a two-year period of routine NetCARDIO implementation (July 2002 to June 2004) and compared with data from an immediately preceding period of equal duration (January 2000 to December 2001).

Results: During the NetCARDIO period, 163 $\pm$ 17 coronary procedures per month were performed vs. 77 $\pm$ 15 during the control period ($p < 0.001$). Percutaneous coronary intervention was delivered 'ad hoc' in 88% of eligible patients vs. 45% ($p < 0.001$). Mean fluoroscopy time per coronary lesion treated decreased from 594 $\pm$ 82 s to 540 $\pm$ 94 s ($p < 0.001$). Annual radiation exposure of expert interventionists was decreased by 22%. Electronic storage significantly reduced archiving costs.

Conclusions: Real-time multimodal services sharing combined with powerful database capabilities is feasible through a web-based structure, significantly enhancing performance and cost-effectiveness of ICF. Further research is needed to promote integration of additional data sources and services.

Keywords

Medical services integration, medical informatics, Java, JMF, radiation exposure, interventional cardiology, heath services research, cost analysis, collaborative services, medical education, hybrid systems

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1. Introduction

In recent years, advances in catheter technology and adjunctive drug therapy have led to widespread implementation of an invasive diagnostic and therapeutic approach in patients with coronary artery disease, thus considerably increasing the workload of Interventional Cardiology Facilities (ICF) [1].

Despite satisfactory outcomes after coronary angioplasty and growing experience even in high-risk lesions and multivessel disease [2], selection of appropriate therapeutic strategy (i.e. interventional or surgical revascularization) still necessitates careful review of imaging and clinical data in a substantial proportion of patients, and in certain cases, decision support by a cardiac surgeon. In conventional workflow, these plausible delays often lead to deferral of angioplasty immediately after diagnostic angiography (which is usually referred to as 'ad hoc' intervention). For patients who are eventually eligible for interventional revascularization, this results in an additional procedure, thus increasing patient discomfort, length of hospitalization, and costs [3].

On the other hand, real-time guidance from an experienced interventionist throughout diagnostic and therapeutic procedures is essential in order to optimize outcomes, especially in complex cases. However, occupational radiation dose constraints could easily be exceeded by continuous physical presence in the catheterization laboratory, especially when senior interventionists are working for several years in a high-volume center [4].

Despite intensive research in this direction, the adoption of such systems in everyday workflow is limited [5, 6], mainly due to substantial difficulties in the integration of services [7, 8]. While expensive dedicated data sharing systems are devoid of distributing and integrating capabilities [9, 10], the employment of already available connections often suffers from inadequate bandwidth, thus precluding real-time image sharing [11]. Moreover, vendor- or platform-dependent solutions result in additional costs and limited expandability [5, 12]. Hence, most of the current projects are based mainly on two simple modes: "store and forward" and "real-time" videoconferencing [13].

Considering the above, we conclude that the heterogeneous nature of ICF requirements demand comprehensive data management and real-time services sharing in order to achieve efficacy, safety, quality improvement and cost-effectiveness [7, 14, 15].

2. Objectives

We propose an integrated system (NetCARDIO) powered by Java technology, which is able to support diverse collaborative services and communications.

Moreover, we investigate the feasibility and effectiveness of this system in a high-volume referral medical center. Our goal was to 1) optimize the triage of patients; 2) support collaboration; 3) enhance educational services sharing; 4) reduce radiation exposure; and 5) improve overall performance and cost-effectiveness of ICF.

3. Methods

3.1 System Services and Process Model

The NetCARDIO is a hybrid system designed to integrate heterogeneous syn-

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chronous and asynchronous services in a common platform to support essential collaborative services. Taking into account the heterogeneous nature of the modern ICF requirements, we adopted a hybrid design (Fig. 1) to span different network technologies, including the Internet [16].

The proposed system is able to simultaneously support three distinct services:

- **Telementoring:** This service enables an experienced interventionist to support the on duty cardiologist in real-time during the procedure on-site via a direct cable connection with the catheterization laboratory. It allows for optimization of outcomes, especially in complex cases, while radiation exposure of senior interventionists is significantly reduced.
- **Telemonitoring:** This service provides authorized telemonitoring. Especially it provides remote near synchronous (< 150 ms) and asynchronous data monitoring over LAN to enable decision support and synchronous educational activities.
- **Multimedia Data Management:** Finally, the multimedia data management service facilitates asynchronous e-learning and management of administrative, clinical, and imaging patient data (Fig. 3). Importantly, it enables senior cardiologists to review and discuss each clinical case along with the respective angiographic findings with cardiology fellows and medical students.

Depending on services access, after login, the user has to select among the available services enumerated by the common interface, according to his/her rights and the connection (Internet, LAN or Direct Cable S-Video and Audio-S/A connection).

When a new patient is admitted to the ICF, the reception creates (or updates) a patient-oriented record with demographic and administrative data. Prior to catheterization, the medical team of the ICF enters (or updates) data regarding patient history, physical examination, and previous investigations. Afterwards, the on-duty interventionist proceeds to the diagnostic angiography. The supervisor of the ICF (i.e. an experienced interventionist) is able to directly view and comment on the findings or give additional instructions. In cases where the therapeutic decision is not straightforward, the supervisor can review data from the patient folder or discuss the findings with a remote consultant (e.g. a cardiac surgeon). In addition, on-line educational activities are also supported. Finally, the patient folder is updated with the catheterization report (i.e. the interpretation of angiography plus details of the angioplasty procedure, if applicable). When the patient completes the procedure, he/she is transferred to the cardiology ward or coronary care unit until discharge. During that time, as well as after discharge, the medical team can update the patient folder with follow-up data. Off-line review is always available for medical or educational purposes. A schematic overview of the data process model is presented in Figure 2.

3.2 System Development

The system is powered by Servlet/Java Server Pages technology (Sun Microsystems, Inc.) and is implemented by a MySQL database (MySQL AB) for back-end data processing [17, 18]. The development team consisted of a medical physicist, an IT expert, and a senior interventional cardiologist. The system was developed as part of a research project.

3.2.1 Data Management Module (DMM)

The data management module enables the following operations: register, login, request ID, insert/find/view/update patient data, open/close multimedia patient data, transfer media to specific folder, and post additional comments. All data pertinent to the catheterization procedure are transcribed into the record (contrast agent, angiography catheters, angioplasty catheters

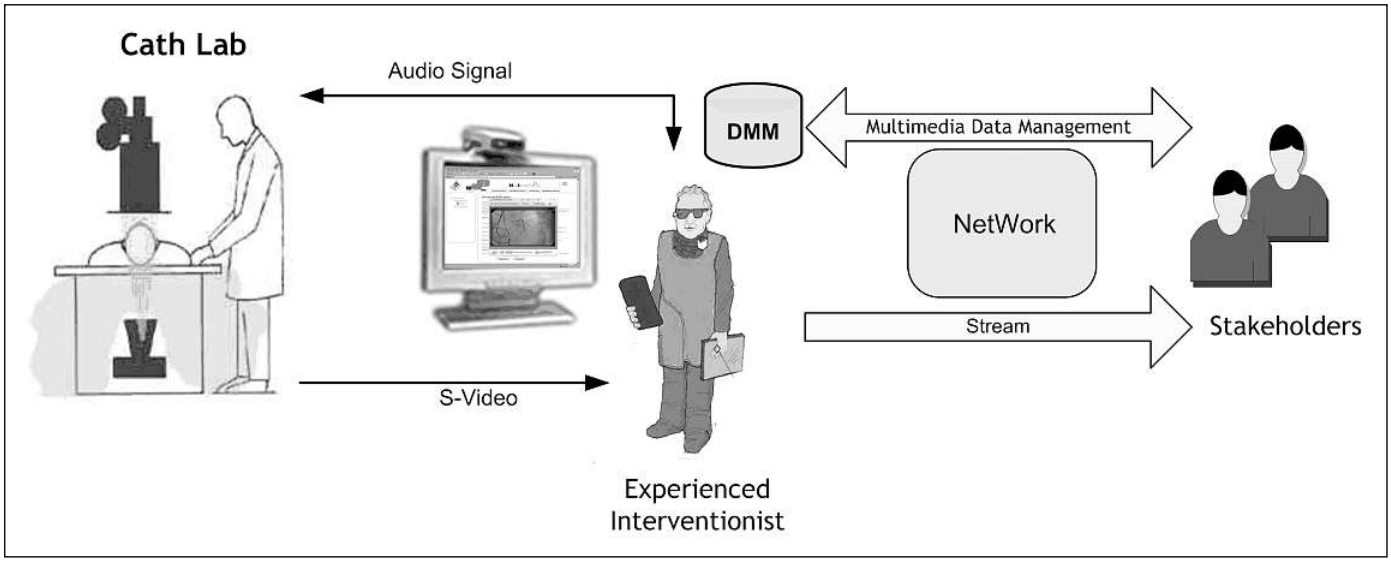

Fig. 1 NetCARDIO architecture

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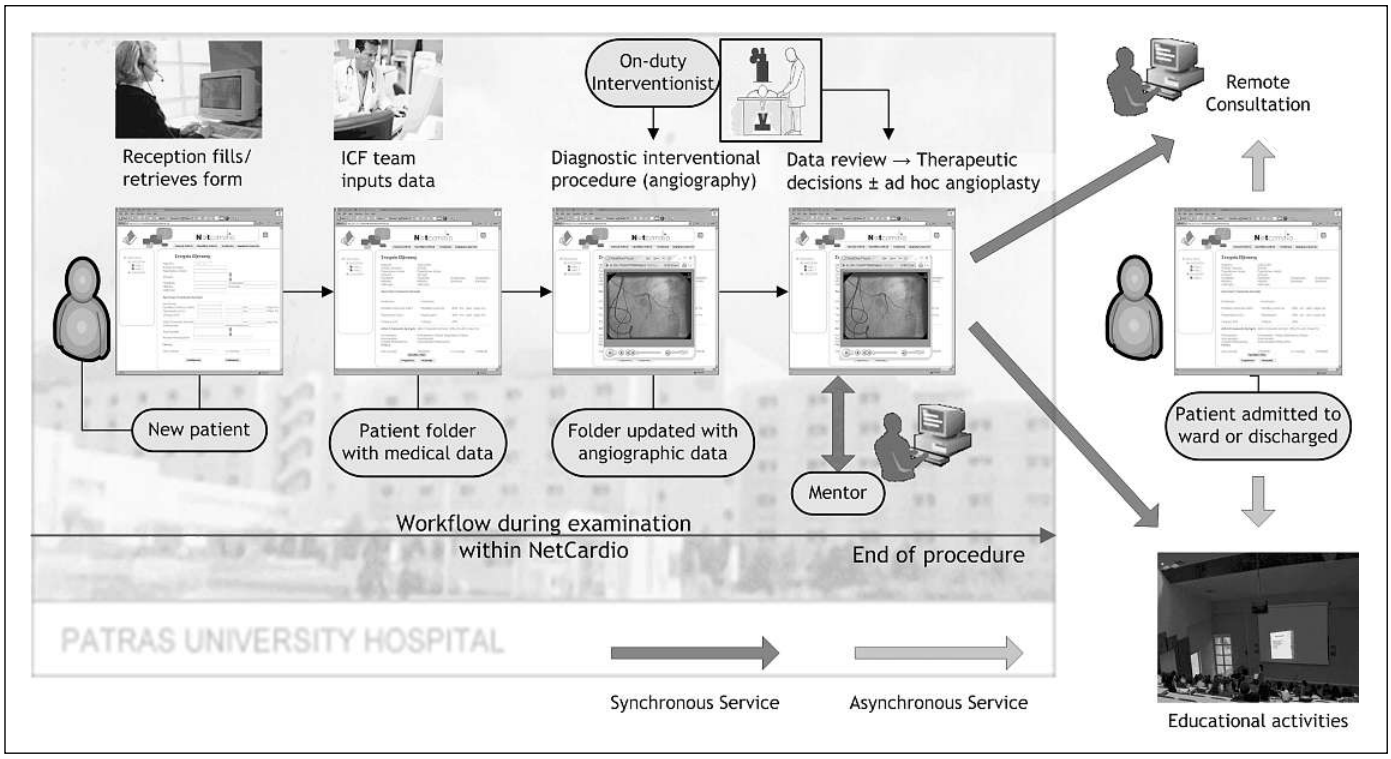

Fig. 2 Data process model

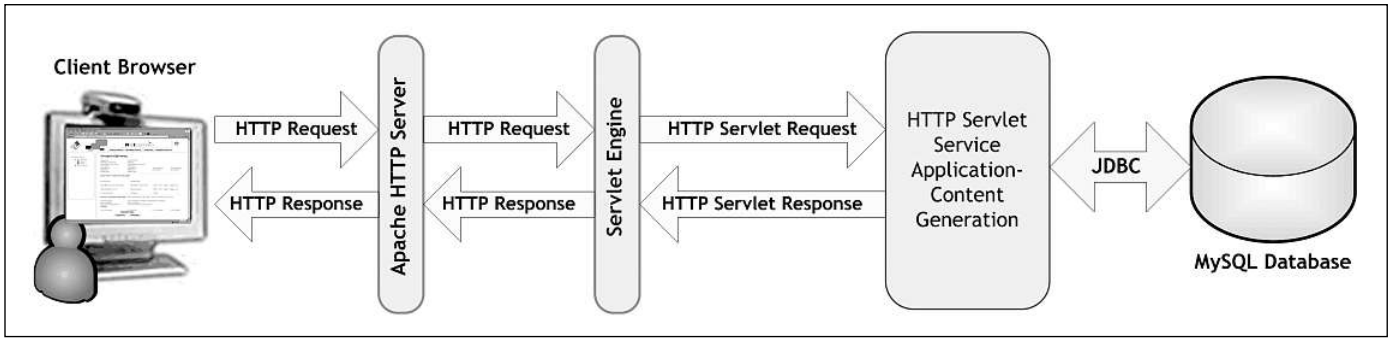

Fig. 3 Data management module

and stents if applicable etc.). Patient identification information (ID) is a key component, which is identical in all subsystems in order to link data to the correct patient.

The module is a web-based application encompassing all data management functionalities provided by the system. The user interface was developed in HTML, with Java Servlets enabling the generation of dynamic web pages using a request-response mechanism (Fig. 3). We selected Apache Tomcat v 4.1 (Apache Software Foundation) as the Servlet/JSP engine for structuring the online module [19]. Connection with MySQL database was established using Java Database Connectivity (JDBC) [20].

3.2.2 JMF and Streaming Module

In order to achieve distributed data monitoring capabilities, we selected Java Media Framework (JMF) v2.1.1 as the most versatile solution (Sun Microsystems, Inc.). NetCARDIO utilizes JMF Application Programming Interface (API) in order to enable authorized users to input, process, store and send streaming media over an IP-based network connection [21] (Fig. 4).

The main system node, located in the office of the head of the department, captures live video and audio. Capture is the input phase of our media-processing module. The capture devices are the microphone and the video capture card. The format of a captured media stream depends on the processing performed by the capture device.

In the first part of the dataflow, this module captures live audio and/or video, processes and transmits them across a net-

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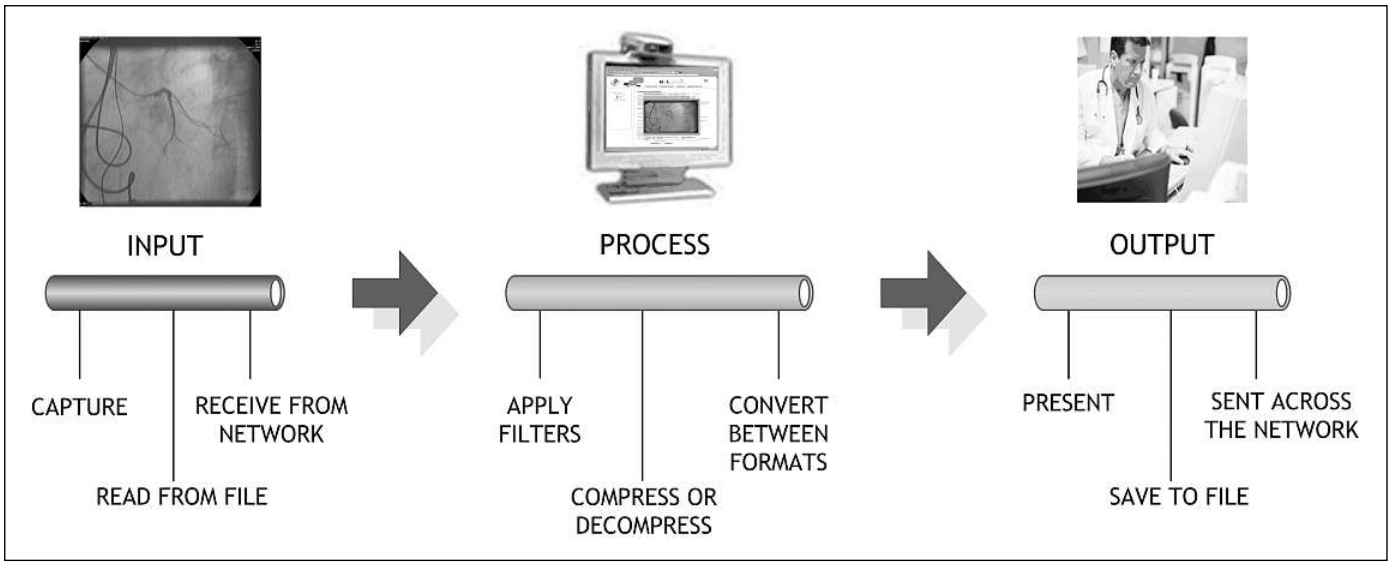

Fig. 4 Media processing model

work using a separate Real Time Protocol (RTP) session for each media type. Incoming RTP streams can be played locally, stored to a file, or both. RTP provides end-to-end network transport functions suitable for applications which transmit real-time data, such as audio, video or simulation data, over multicast or unicast network services.

At the stakeholder site, incoming remote RTP streams can be played locally, stored to a file, or both, through an RTP Session Manager for each incoming media type. The Session Manager is one of the core elements of the main module. This entity is used to coordinate an RTP session. It keeps track of the session participants and the streams that are being transmitted. It also allows defining methods that enable applications to initialize and start participating in a session, remove individual streams created by the application, and close the entire session.

We also developed a specific entity for stream receiving by the session manager. The format and rate of captured media streams are easily modifiable through capture controls. This entity acts as a player able to process the incoming stream and renders it at a precise time on a device which supports the presented media. JMF defines DataSources as a data abstraction that encapsulates the media stream much like a video tape. To manage the transfer of media-content a DataSource encapsulates both the location of media, protocol and software used to deliver the media. The entire data streaming procedure is presented in Figure 5.

3.3 Data Collection and Statistical Analysis

We collected data regarding total number of coronary diagnostic (angiography) and therapeutic (angioplasty) procedures per month, percentage of patients proceeding to angioplasty, percentage of angioplasty procedures performed 'ad hoc' (immediately following diagnostic angiography) and procedural fluoroscopy times for two distinct periods. We selected as 'control period' an immediately preceding two-year period (January 2000 through December 2001) to minimize bias due to advances and changing practice in interventional cardiology. We

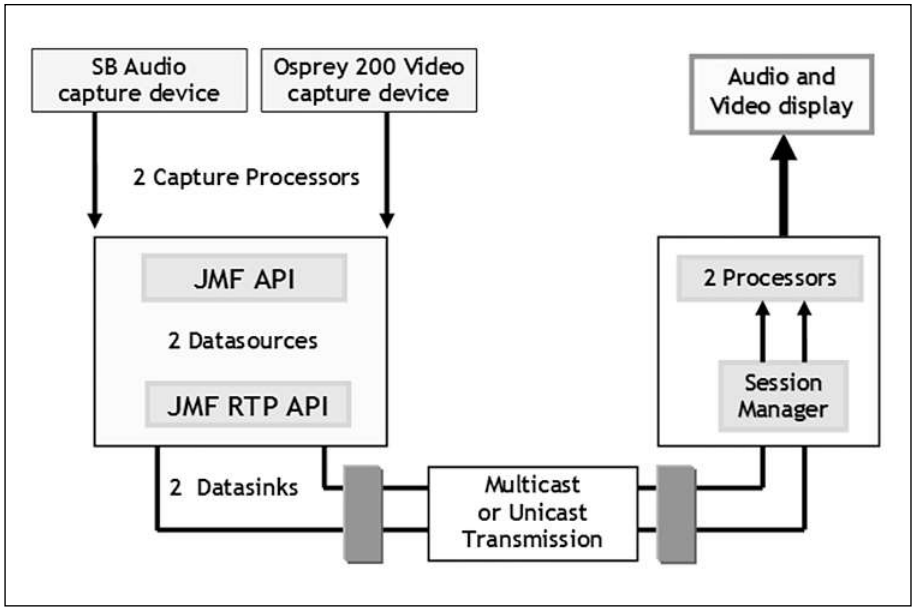

Fig. 5 Streaming architecture

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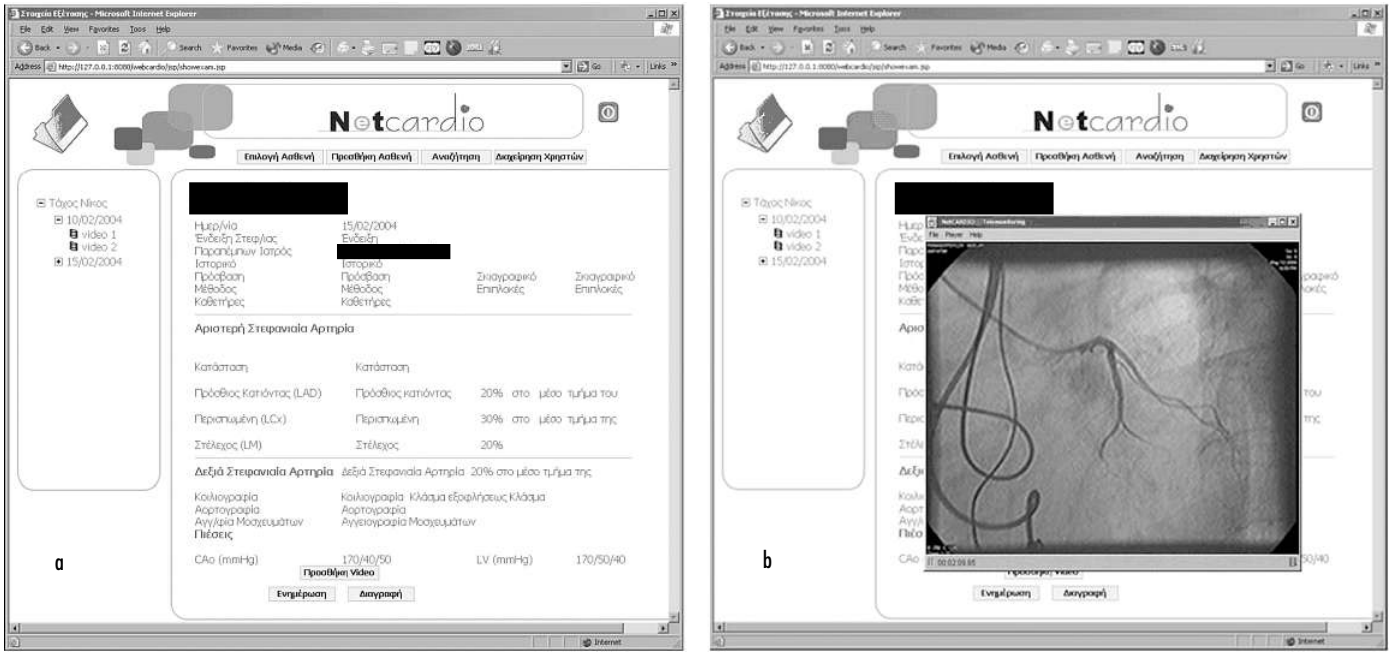

Fig. 6 Snapshots from patient data file (a) and streaming interface (b)

also allowed for a learning curve immediately after system installation in order to achieve stationarity and collected data for a two-year period of routine NetCARDIO implementation (July 2002 through June 2004). We adjusted the fluoroscopy time of angioplasty sessions for the number of coronary lesions attempted per session to account, at least partially, for intervention complexity. We also recorded the number of interventional cardiologists performing angioplasty procedures as independent operators. Catheterization laboratory logbooks served as source documents for data collection. Data on personal radiation exposure were provided by thermoluminescent dosimeters analyzed by the central national laboratory. Data on archiving costs were obtained from the administrative service of ICF. An interview with NetCARDIO clinical stakeholders was scheduled to be held at the end of the evaluation period.

All continuous parameters are expressed as mean ± SD and compared by Student's t-test. Percentages were compared by the chi-square statistic. All analyses were performed with SPSS 13.0 statistical package (SPSS, Inc.).

Table 1 ICF performance measures before and after NetCARDIO implementation

Parameter	Jan 2000 to Dec 2001	Jul 2002 to Jun 2004	*p* value
Coronary procedures (angiography & PCI), per month	77 ± 15	163 ± 17	$p < 0.001$
Percutaneous coronary interventions (PCI), per month	15 ± 5	62 ± 7	$p < 0.001$
Patients with PCI following angiography, * %	19.3	37.8	$p < 0.001$
PCI procedures performed 'ad hoc', † %	44.8	87.7	$p < 0.001$
Coronary lesions attempted per PCI			
1	73.8%	74.8%	ns
2	22.8%	22.5%	
3+	3.4%	2.7%	
Fluoroscopy time per lesion attempted, (s)	594 ± 82	540 ± 94	$p < 0.001$
Interventionists performing PCI, n	2	6	
Archiving cost per procedure, €	8	1	

*refers to patients treated with PCI within two months
†refers to PCI procedures immediately after diagnostic angiography

4. Results

Collected data regarding coronary procedures, fluoroscopy time and archiving costs are summarized and compared in Table 1. The term 'coronary lesions attempted per PCI' refers to the number of coronary lesions that were intended to be treated during each angioplasty session. Although not comprehensive, it is a rough measure of procedure complexity.

During the evaluation period of our project:

- 3521 integrated records (diagnosis, video, etc.) were imported successfully in the established database.

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- 1311 services activations were recorded to the log file of the server.
- 42 of these procedures were fully collaborative, with simultaneous consultation with a cardiac or vascular surgeon.

Following the evaluation period, a general interview was conducted with NetCARDIO clinical stakeholders. Stakeholders included interventional cardiologists (n = 6, including the two supervising interventionists), interventional cardiology fellows (n = 2), and cardiology fellows rotating in the ICF (n = 8). The general remarks that emerged from the interviews with the 16 clinicians were that NetCARDIO is a user-friendly and flexible collaboration environment. They also indicated that the system supports successfully data integration and high quality visual elements, as well as fullmotion video without delays during data streaming. Finally, they noticed that our system is able to act as a dynamic portal supporting ICF training and education.

Hardware costs included a Dell Precision Workstation 340 (Dell Corporation) equipped with an Osprey 200 video capture card (ViewCast Corporation) and a SoundBlaster Audigy 2 (Creative Technologies) audio capture card, amounting to €2000. Software did not add to costs because Java API and MySQL database software are available as open source downloads over the web. Network connections also did not add to cost, since we used the preinstalled hospital intranet.

Migrating to a filmless approach reduced archiving costs by approximately €7 per procedure, leading to estimated annual cost savings of €14,000, mainly due to the considerably lower costs of system maintenance and digital storage media. Before NetCARDIO, each procedure was recorded on 35-mm film and stored by a technician in a special protective can, with an average cost of €8 per procedure. After NetCARDIO implementation, each procedure was recorded on a high-quality recordable compact disc which led to a substantial reduction of the archiving cost to less than €1 per procedure.

Another significant limitation of the film-based approach was the platform-dependency of the film-processing system, leading to three significant disadvantages:

1) Requirement for highly specialized personnel and hardware for maintenance. This caused substantial delays and costs in the case of system malfunction. NetCARDIO uses inexpensive and widely available hardware which can be easily configured by our IT experts at a considerably lower cost.
2) The 35-mm film can only be viewed in dedicated equipment which is usually not available outside an ICF. Recordable CDs with incorporated media viewers can be played on virtually any contemporary PC.
3) When medical or legal reasons necessitate producing a copy of the film, we have to refer the film to specialized laboratories, which as a rule are not available in hospitals. Digital reproduction can be accomplished in most modern PC machines.

Telementoring led to expedited distribution of knowledge and allowed for a more active participation of experienced cardiologists with medium-level expertise in interventional procedures. As a result, at the end of the second period under investigation, four additional cardiologists were able to perform angioplasty as independent operators, besides standard diagnostic angiography.

This also resulted in a decrease in personal radiation exposure of the two senior interventionists by 22% (cumulative dose 2000-2001: 6.7 mSv, cumulative dose 2000-2001: 5.2 mSv).

5. Discussion

During the evaluation phase of our project, we have observed that a hybrid-services system tuned for modern interventional cardiology requirements has a substantial impact on everyday practice. Notwithstanding advances in the field, the twofold increase in procedural rates, in percentage of patients undergoing PCI and most importantly, in percentage of 'ad hoc' interventions, provides evidence of improved service quality.

Increased productivity has straightforward explanations. Real-time expert guidance and easy integration of both clinical and imaging data expedites decision making on safe grounds and subsequently improves patient triage. During the film era, evaluation at the time of diagnostic angiography for possible coronary angioplasty was actually feasible – on the screen displaying the real-time angiogram in the catheterization laboratory. However, this was a double-edged sword in complex cases due to several limitations: restrictions that apply in the laboratory do not allow for scrutiny of the displayed images or for convenient re-evaluation of patient data (i.e. electrocardiograms, echocardiograms, nuclear imaging scans), which is of paramount importance in certain cases. Moreover, expert opinion was not continuously available during angiography due to radiation exposure limitations. On the other hand, off-screen evaluation of angiography film on special projection equipment required a definite amount of time due to film processing issues. In the meantime, candidates for coronary angioplasty had to wait with the arterial sheaths in place, thus increasing patient discomfort and substantially slowing down the schedule. As an alternative, a second session had to be planned, thus resulting in prolonged hospitalization or readmission. In contrast, NetCARDIO allows for careful evaluation of real-time angiography images within a user-friendly web-based system which supports side-by-side comparisons with previous angiograms and non-invasive investigations. Furthermore, the elimination of radiation issues allows for virtually continuous monitoring of non-emergency diagnostic procedures by a senior interventionist, thus substantially speeding up the selection of the appropriate strategy. In addition, immediate distribution of critical information is also supported. Active involvement under continuous telementoring gradually enabled cardiologists with medium-level expertise in coronary angioplasty to operate independently, thus significantly reducing workload of expert interventionists.

The interpretation of another important finding, namely the twofold increase in per-

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cutaneous revascularization rates, is more complicated. Selection of patients for coronary angiography and possible subsequent coronary angioplasty in our center is based on the concurrent guidelines proposed by the respective working group of the American College of Cardiology/American Heart Association [22, 23]. During the period of our investigation, results of controlled randomized trials encouraged multivessel coronary angioplasty as an acceptable alternative to coronary bypass surgery [24, 25]. Although difficult to measure its impact, the widespread use of drug-eluting stents (which significantly reduce restenosis rates at the site of angioplasty when compared to conventional stents) might also have influenced revascularization decisions. However, complexity of procedures, as reflected by the number of lesions attempted per angioplasty session, did not change after NetCARDIO implementation. Hence, the adoption of 'ad hoc' intervention in almost 90% of eligible patients, besides evolution of guidelines and widespread adoption of early invasive approach in acute coronary syndromes [26, 27], should be equally attributed to elimination of logistic shortcomings regarding data reviewing and expert consultation. Interestingly, transition to an almost universal 'ad hoc' strategy underscored another side effect of the delayed approach: patient attrition. During our 'control' period, less than two-thirds of eligible patients in whom coronary angioplasty was recommended as a planned procedure on an outpatient basis have eventually received treatment. Consequently, we partially attribute higher rates of interventional treatment to a positive influence of the single-session approach.

Interestingly, contrary to what is anticipated during learning curve periods, participation of less experienced operators in complex procedures did not adversely affect fluoroscopy time. Indeed, a significant reduction of mean fluoroscopy time per lesion attempted during angioplasty sessions was observed, indicating that any learning curve effect was completely offset by the positive influence of continuous telementoring and growing operator experience.

In addition, migration to a filmless solution to store and reproduce imaging data by means of widely available hardware and media significantly reduced archiving costs and maintenance time. In addition, the platform-independent nature of this approach substantially enhanced versatility in terms of imaging data storage and distribution.

Another key point of the presented system is that NetCARDIO is able to utilize various codecs to perform data encoding, decoding and compression quality adjustment. Thus, while ensuring wide compatibility (HIS, PACS, RIS) we are able to adjust image quality according to clinical requirements.

A number of previous projects have focused on services that NetCARDIO includes [28, 29], or on point-to-point costly structures guiding individually remote clinicians [30]. Decruyenaere et al. propose a single-service system for data flow management and address designing issues [28]. Hu et al. broadcast on multiple computers event messages establishing a communication within a teleconsultation platform [29]. These approaches provide a) low efficiency in real-time interactions and b) poor accuracy in shared images [31]. Our system is based on a cross-platform collaborative solution to support a number of heterogeneous services. Hence, just one single applet is needed to receive the video and audio stream from the server. One API applet is stored on the server, eliminating the need to install it at the client, enabling stakeholders to choose different transfer rates for the video stream to meet their individual bandwidth limitations.

NetCARDIO should not be regarded merely as a remote visualization tool or a telementoring system. The proposed system is a complete suite that supports synchronous and asynchronous services management locally and remotely and encompasses the entire ICF process including diagnosis, planning and treatment. On the other hand, systems like NetCARDIO and the increasing amount of available bandwidth will be a driving force to the direction of synchronous scenario development in the area of interventional cardiology, including interdepartmental collaboration on complex procedures, development of common clinical protocols, distributed continuous medical education and, finally, collaboration in clinical decisions (e.g. patient referral or transfer). In addition, collaboration on a common solution connects educators and learners and supports new ways in clinical education. To be most effective, medical education should be a seamless part of the real-world workflow.

Although the system is already being used, it is still in progress. Efforts are still required in the direction of established telemedicine sessions. The incorporation of an additional module which would enable the interventionist to immediately notify the on-call cardiac or vascular surgeon or critical care physician, in case of emergency, would be a substantial improvement from a clinical point of view.

We should also notice that although collaborative multicast activities using the presented system within the Public Network (WWW) are theoretically feasible, bandwidth availability and personnel training are issues that must be addressed more definitely in order to allow their widespread adoption and facilitate integration of additional data sources and services. Scalable architecture allows for convenient incorporation of additional codecs and compatibility with future developments in communication protocols. Our future direction is to develop a Java-based DICOM viewer based on the JMF model in order to enable viewing of DICOM images and integration into the HIS.

6. Conclusions

Real-time multimodal services sharing combined with powerful database capabilities is feasible through a web-based structure. In the ICF setting, services integration through this structure results in measurable and substantial benefits. The proposed model exerts a favorable effect on patient triage, radiation exposure, knowledge distribution, overall performance and cost-effectiveness. Further research is needed in the direction of additional data sources and services integration.

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