

## Enterprise-wide PACS: Beyond Radiology, an Architecture to Manage All Medical Images<sup>1</sup>

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**Rationale and Objectives.** Picture archiving and communication systems (PACS) have the vocation to manage all medical images acquired within the hospital. To address the various situations encountered in the imaging specialties, the traditional architecture used for the radiology department has to evolve.

**Materials and Methods.** We present our preliminary results toward an enterprise-wide PACS intended to support all kind of image production in medicine, from biomolecular images to whole-body pictures. Our solution is based on an existing radiologic PACS system from which images are distributed through an electronic patient record to all care facilities. This platform is enriched with a flexible integration framework supporting digital image communication in medicine (DICOM) and DICOM-XML formats. In addition, a generic workflow engine highly customizable is used to drive work processes.

**Results.** Echocardiology; hematology; ear, nose, and throat; and dermatology, including wounds, follow-up is the first implemented extensions outside of radiology.

**Conclusion.** We also propose a global strategy for further developments based on three possible architectures for an enterprise-wide PACS.

**Key Words.** PACS; diagnostic images; image distribution; electronic patient record; workflow engine.

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Picture archiving and communication systems (PACS) are now considered as the gold standard by the radiologist community and are widely implemented even at very large scales (1). The PACS industry is mature and offers archiving solutions and reading stations that fulfill the needs of the users in radiology. The image distribution through the electronic patient record is generally adopted (2,3). Moreover, the integrating health care enterprise initiative provides a solid framework to ensure a good integration between the various components of a hospital information system, such as the clinical information system

and its subcomponents, such as radiology information system, computerized provider order entry, the admission-discharge transfer component, billing components, or scheduling. The issues at stake are now mostly outside radiology.

With the increasing medical complexity of an aging population and the need for an integrated electronic patient record (EPR), the patient is taken in charge by a continuously increasing number of different care specialties. As a result, the quantity and variety of information generated are exploding. The distribution of consolidated patient information between departments is therefore a critical point and sets a new challenge for the information systems. We can expect that better information in terms of quality and quantity will provide new perspectives: it will ultimately improve the outcome for the patient and it will foster a collegial approach among clinicians.

Clinical information systems are expected to address all hospital imaging acquisitions. Indeed, there are many

*Acad Radiol* 2005; 12:1000–1009

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doi:10.1016/j.acra.2005.03.075

specialties beyond radiology that produce medically relevant images. Those specialties understand the benefit from the digital storage of their images within a unified system. PACS can provide help for the patient follow-ups and the creation of teaching and research materials. Observations in our institution showed the following specialties as first targets for this extended PACS: cardiology; dermatology; ophthalmology; surgery; ear nose, and throat; hematology; pathology; gastroenterology; obstetrics; gynecology; and surgery. So far, those specialties had only access to very specific solutions. Those solutions usually managed images locally without any real perspective for interdepartment communication. For example, in the pathology specialty, a commercial solution covering the following tasks could be found: image acquisition from a network of microscopes, reading, and reporting. Images, however, could not be exported or retrieved from external sources.

In place of the large number of information systems addressing the specific needs of each specialty, we envisage an enterprise PACS storing all diagnostic images acquired within the hospital with a unique distribution point via the EPR platform. Some institutions have also adopted a similar approach such as the US Department of Veteran Affairs (4,5). The challenge is to develop a common system that is flexible enough to address the specificities of each specialty. Most commercial PACS have been developed for radiology and require some structural evolution to fulfil this ambition. PACS has definitely vocation to extend beyond the radiologic images to become the common platform for hospital-wide distribution of all images. We will depict here initial practical achievements in that direction performed at the University Hospitals of Geneva.

## CLINICAL MOTIVATIONS

Medical diagnosis is commonly based on the synthesis of patient related information. With the strong increase of the diagnostic tools and therapeutic and monitoring parameters, this synthesis is becoming more and more challenging. Therefore, there is an acute need for tools aimed at easing this medical synthesis and allowing an efficient comparison of the different results. An enterprise PACS will certainly have a beneficial impact on the clinical workflow. It offers all the advantages of a traditional radiologic PACS (large availability and ubiquity of the images, reliable retrieval of old exams, improved navigation

inside the image series) and new opportunities, such as the following.

- It allows intermodality comparison by easing the images registration. For instance, the recent development of new imaging techniques (positron emission tomography-computed tomography [CT], functional magnetic resonance imaging [MRI]) will offer multidisciplinary collaboration between radiologists and cardiologists (6). In that respect, PACS can be a fostering force for teamwork.
- It reinforces the diagnostic power of a traditional PACS by offering to the clinicians a complete view of the patient multimedia record. Finally, it may increase the strength of content-based image retrieval systems by creating extended image databases (7).
- It helps the collaboration inside the medical team. Access to all imaging specialties is a great tool for multidisciplinary clinical rounds. In addition, the clinical rounds are more interactive as every imaging specialists can comment on his or her diagnostic contribution using digital images obtained directly from PACS.
- It will build and keep the coherence between multimedia clinical information and textual information by implementing a unique framework for multimedia data. The systematic association of the medical images to the report should significantly decrease transmission error because clinicians will have access to both images and specialist's reports.

## CURRENT SITUATION: A SPECIALIZED MARKET

Image management tends to be implemented in the various imaging specialties. Even in the surgery theater, where information technology (IT) has recently appeared, the development of surgical laparoscopy pushes for a better integrated organization, including video management (8). However, the commercial solutions address the specific needs of each imaging specialties such as ear, nose, and throat; pathology; or dermatology with independent storage systems that does not communicate with other image management solutions. As a consequence, none of them offers a global solution fulfilling the needs and matching the situation variety encountered in all imaging services. The only exception is the current trend toward a unified PACS covering both radiology and cardiology activities.

Another problem remains the frequent lack of a well-structured departmental information system equivalent to a radiology information system in radiology and supporting the scheduling and patient management activities.

## METHOD: OUR EXPERIENCE

The Geneva University Hospitals is a consortium of hospitals, comprising more than 2,000 beds; 5,000 care providers; more than 45,000 admissions; and 450,000 outpatient visits each year. It covers the whole range of inpatient and outpatient care, from primary to tertiary facilities. We took advantage of our existing PACS (9) and of our in-house EPR to offer a unique access to all medical images throughout the hospital.

Our core imaging facilities rely on a commercial PACS system (Image Devices GmbH, Aachen and Idstein, Germany [10]) deployed within the radiology department since 1999 and on a hospital-wide distribution through our EPR application (10).

### A Hospital-wide PACS for Radiologic Images

PACS is widely used in a daily routine and is fully accepted by the radiologists of our hospital. The key success factor has been the intuitive and productive tools supplied by the soft-copy software (automated viewing protocols, contextual menus). PACS introduction significantly improved the radiologic workflow by offering a direct reading after acquisition. Eight clinical rounds are daily performed in digital way (internal medicine, neurology, surgery), and CT and MRI are fully read using soft copy.

This system stores 20,000 images daily that are delivered by 33 modalities on a three-tier hierarchical storage: a 2-terabyte (TB) magnetic disk cache, a 5-TB near-line archive based on optical disk and a 17-TB tape backup. As a result, 95% of image production in radiology is digital and effectively stored on the PACS.

Our PACS architecture is undertaking a complete renewal. With storage costs decreasing, it becomes financially viable to archive images online on magnetic disks. New magnetic disk technologies, such as Serial-ATA disks, present a good cost:benefit ratio, with the price around US\$6,000–8,000 per TB. We are moving to a “pay as you grow model:” we will add magnetic storage every 3 years to cover our needs (5 TB/year in radiology).

This PACS system, along with an open integration framework and a generic workflow engine described later

in this article, will be used as a basis for an enterprise PACS.

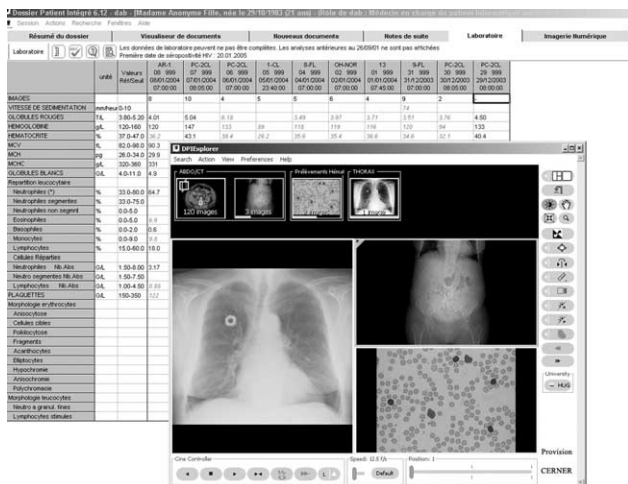
### Integrated Electronic Patient Record

The current clinical information system allows access to more than 4 million medical documents online, including laboratory results and structured clinical documentation (11) (Figure 1). It provides a unified provider order entry system for drug ordering, care, and radiology procedures. This system also generates a structured clinical documentation system for nurses based on international classifications. The clinical information system is a distributed component based system in a three-tier architecture. All communications between components use authenticated protocols and web services (12). They are mostly event-oriented based on a publish-subscribe paradigm. The use of web services for all components and a shared semantics allows a consolidated view of medical information provided by heterogeneous sources. For example, radiology reports or hematology laboratory results can be viewed in relation to their images, including microscopic examination of blood smears.

Clinicians can display the medical images in a Java applet image viewer directly launched from the PACS and fully embedded in the EPR user interface. The content of the applet is driven by the middleware, ensuring the correct relationship between images and other data.

This PACS image viewer is now widely used in our daily routine. It offers measurement tools (two-dimensional and region of interest) or predefined window/level settings and advanced imaging capabilities through our own visualization and processing plug-ins, such as a multiplanar reconstruction navigation and some semiautomated quantification tools (measurements of volume tumors via a three-dimensional segmentation). We agreed with our commercial supplier to share the same data representation structure to transmit image data sets. This allows us to develop specific extensions needed by clinicians. The Java viewer is displayed in less than 20 seconds and images are progressively retrieved when the user browses an image series. The retrieval speed is approximately 5 CT images/second, which is definitely too low for very large image series. For that reason, we are encouraging the distribution of only the key images selected by radiologists.

A recent satisfaction survey submitted to 80 clinicians showed that 77% of respondents regularly use the PACS image viewer. Satisfaction level is 4 on a scale of 0 to 6, and 82% of respondents would accept the complete re-



**Figure 1.** The electronic patient record (EPR) and its graphical user interface with laboratory results and image display. This figure is a typical view of the EPR used in our facility. The EPR is built using a legacy container that encapsulates a web browser. We can use most web browsers. The container takes care of managing the smart card, ensuring proper communications, and blocking or controlling some functions usually found in browsers, such as “save as” and “print” for medico-legal reasons. It also blocks, when needed, navigation keys such as “back” and “forward,” improving the control for sensitive pages such as order entry. It also ensures that no critical data are kept locally. Finally, and most important, the container manages the global session coherence making sure that all data available for one patient are consolidated. Each tab visible on the figure is made of at least one web page. What is selected is the lab tab. At the bottom of the lab tab, each domain of lab can be selected, in the case hematology. The first line of the worksheet is devoted to display how many images (usually blood smears) is available. By clicking on this number, the corresponding images can be seen in the same PACS viewer as the other DICOM images (PACS supplier: Image Devices GmbH, Aachen and Idstein, Germany).

removal of film hardcopies, although 54% request some improvements. The required improvements most often mentioned were speed performance and a better adaptation to the workplace, such as the surgical theater. The less enthusiast clinicians were the orthopedists, mostly because the viewer lacks some of the surgical planning tools that they need. The most enthusiasts were neurosurgeons and neurologists who were already intensively using the viewer, especially for their clinical conferences.

This type of satisfaction survey is an excellent tool to quantify the acceptance of IT tools and to help the IT services to target the area of weaknesses of their system. Relying on informal feedback and perception should be confirmed by a more rigorous approach. Such a survey has proven also useful as a communication tool with the administration of the hospital.

## An Integration Framework Relying on DICOM and a DICOM-XML Format

We mainly rely on the DICOM (digital image communication in medicine) standard to integrate new imaging sources. This standardization process was initially only focused on radiology. However, DICOM has considerably improved recently and now encompasses the different imaging specialities. For instance, the cardiology activities (catheterization, ultrasound, nuclear medicine) benefit from the recent improvements introduced in 2003: the “catheterization lab structured report” supplement defines new templates of various reports and the “echocardiography procedure report” supplement enables the transfer of the measurements and codes from ultrasound machines.

Those improvements will definitely smooth the diagnosis workflow in a multisupplier environment. For instance, measurements may be done on the fly directly on the ultrasounds and transferred to the review station. At that level, the cardiologist will complete a structured report based on predefined templates automatically filled with measurements.

DICOM also covers nonradiologic images, also referred as visible-light images. These extensions apply to endoscopy and microscopy images in addition to simple photographic images obtained in dermatology or ophthalmology for instance.

Since 2000, a new level in integration has been reached with integrating hospital enterprise. This initiative provides a solid framework to ensure a seamless integration of the different systems. It promotes a coordinated use of established standards—such as DICOM and HL7—to address specific clinical needs in support of optimal patient care. It defines 12 integration profiles covering the phases of the workflow such as patient admission, scheduling, order entry, or image acquisition. The imaging industry has started to adopt its recommendations even if too many differences of implementation remain among suppliers.

In parallel to DICOM, we also adopted a lighter format based on XML because many imaging suppliers do not support DICOM outside of radiology and cardiology. The rationale is that a DICOM-XML-like format is more easily accepted because it is easier to implement. Moreover, it is compliant to the federative middleware applied within our institution (13). Different initiatives have been pursued to encode the standard in XML (14,15). Basically our DICOM-XML format represents a simplified DICOM information model: each XML tag matches a corresponding DICOM data element, but we only retain the most

relevant information (Figure 2). Images are sent enclosed as JPEG or TIFF formats. We implemented a DICOM-XML to DICOM converter broker to communicate with our PACS.

### A Generic Workflow Engine to Match the Specialties' Needs

Extending the coverage of the PACS to other image producer could not be accompanied with a parallel extension of the radiology information system, and we decided to rely on a generic workflow engine. This approach allows us to consolidate and improve many heterogeneous although interconnected workflows. The reading practices differs according to the imaging specialty (16). For instance, in cardiology, images are first read by a resident and then reviewed by a senior. The report will be produced once discussed. As a consequence, our system has to be flexible enough to support various workflows. Moreover, the workflow engine has been also used to support some integration components such as HL7 ordering request messages to interface mini-PACS with our EPR.

We define a "workflow" as a sequence of tasks involving different actors. A task can be performed:

- manually: it needs a user interaction (for instance, a clinician needs to sign a report to approve it) or
- automatically: the task can be triggered and executed automatically without any user interaction (for instance, an image export to the PACS can be automatically executed after acquisition).

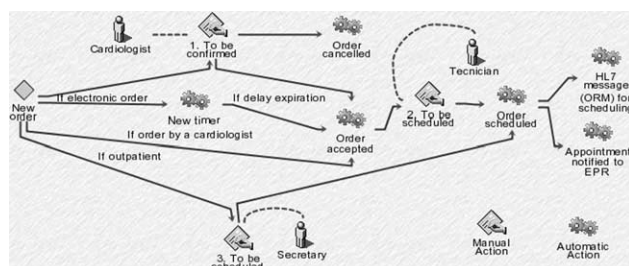
To computerize a workflow, we acquired a Business Process Management System (17) (W4 SA, Palaiseau Cedex, France), also called a workflow engine. This workflow engine is a generic piece of software that defines, manages, and executes workflows.

A new workflow is implemented according to the following steps:

- process definition graphically designed by a functional expert (Figure 3),
- implementation (integration connector, database connections),
- process deployment through the workflow engine, and
- the workflow statistical analysis is used to highlight the potential bottlenecks to be adjusted in the process design.

```
<DICOM_XML>
<APPLICATION>Application name</APPLICATION>
<PROFILE>Imaging service: haematology</PROFILE>
<PATIENT>
  <DE GRP="10" ELT="10">Last Name</DE> ..... (10,10) Patient Name
  <DE GRP="10" ELT="20">Patient Id</DE> ..... (10,20) Patient Id
</STUDY>
  <DE GRP="8" ELT="20">Study date</DE> ..... (8, 20) Study Date
  <DE GRP="8" ELT="50">Accession Number</DE> ..... (8, 50) Accession Number
  <DE GRP="8" ELT="1030">Study desc. Hemogram</DE> ..... (8,1030) Study Description
</SERIE>
  <DE GRP="8" ELT="60">Modality OT</DE> ..... (8,60) Modality
  <DE GRP="8" ELT="21">Series date</DE>
  <DE GRP="8" ELT="103e">Series desc.:color blue</DE>... (8,103e) Series Description
  <DE GRP="20" ELT="11">Series number: 1</DE>.....(20,11) Series Number
</IMAGE>
  <DE GRP="8" ELT="22">Acquisition date</DE> ..... (8,22) Acquisition Date
  <DE GRP="7fe0" ELT="10">Path to image file</DE> .. (7fe0,10) Pixel Data
</IMAGE>
```

**Figure 2.** A simplified example of the digital image communication in medicine (DICOM)-XML structure mapping a DICOM structure.



**Figure 3.** Example of a workflow design. A manual action needs an user interaction. This example depicts the workflow of an examination preparation in cardiology. A potential bottleneck existed if the cardiologist did not check his or her work list (task 1: order to be confirmed). The solution we implemented is the generation of a default approval after a time out. When a default approval is notified to the technician, he or she has to ask the oral approval of a cardiologist.

The workflow process can be updated at any time to smooth the clinical work: for example, a task can be removed for simplification or a task can be delegated (eg, approval of a new imaging request that can be delegated to technicians). Moreover, the workflow engine can automatically notify other systems of the exam status. This feature allows all actors involved within the workflow to be informed in real time of the result availability (images or reports).

### RESULTS: FIRST OUTCOMES OF OUR IMPLEMENTATION OF AN ENTERPRISE PACS

We used three approaches to connect the different imaging specialties to our enterprise PACS. Each of them was adapted to the specific situation of the specialty.

- A hierarchical model coupling multiple mini-PACS to the enterprise PACS: each mini-PACS fulfils the needs

of its medical specialty and stores the most recent images, whereas the enterprise PACS archives for the long-term. The rationale for the mini-PACS is to address the specific needs in terms of processing and quantification tools (eg, cardiology) and to provide high performance. According to the imaging speciality, the mini-PACS is either a single acquisition station or a network of stations connected to a temporary storage server. This approach is well suited to medical specialties needing some sophisticated processing tools and advanced structured reports combining text, customized measurements, and images. The challenge of this approach is to deliver an integrated workflow between the EPR, the mini-PACS, and the enterprise PACS, especially for imaging departments in which we could not rely on existing local scheduling and order filler solutions. The solution came from our workflow engine: we implemented some work processes to fulfil the tasks of an order filler and a simple scheduling system. We could then deliver an integrated loop workflow including order entry within the EPR, order validation, scheduling, image acquisition, reading and report on the mini-PACS and results transfer to EPR and PACS. We chose this strategy for the echocardiography laboratory; ear, nose, and throat; pathology (Infologic, Borelles-Valence, France); and gastrointestinal section (Olympus, Tokyo, Japan).

- Storage via the EPR: images are directly uploaded from the EPR and then sent to the enterprise PACS. In that case, the EPR acts as an acquisition software and supplies image uploads to the PACS. These upload utilities are available at meaningful stages of the patient care process: consultation and diagnostic investigations. This strategy allows the images to be associated with a given result such as reports or labs result. This solution is well suited to medical specialties for which images represent only a part of the medical results. Images will be stored to document a case such as an image of a specimen illustrating a laboratory result. The direct access to the images from the patient report could potentially lead to a better understanding of the diagnosis by the various physicians in charge of the patient. Image storage is performed as a DICOM file on the enterprise PACS. We have applied such an approach in hematology.
- Direct storage to the PACS: the modality directly pushes images to the enterprise PACS. This approach is well suited to medical specialties having a workflow similar to the radiology. An examination includes an image acquisition and reporting needs are similar to

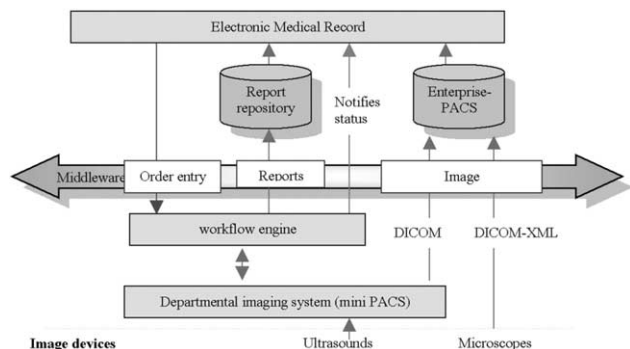
radiology without any specific image processing. This scheme can be applied for instance for ultrasound images in gynecology, neurology, and obstetrics.

### Cardiology

Historically, the first generation of PACS used in cardiology departments addressed the specificities of each laboratory by developing independent multiple systems. At the time, the industry did so to match the existing vertical organization of the labs. Traditional reluctance to share the information encouraged this initial PACS architecture: cardiac angiography management solutions were first introduced, followed later by the ultrasound solution (18). Each lab specific solution or mini-PACS consisted of a long-term storage unit connected to specialized stations.

At the University Hospitals of Geneva, we based our implementation on that historical architecture. However, our mini-PACS are limited to a temporary storage unit connected to the enterprise PACS. The images are then either accessed through a web platform or from the electronic patient record. Thus we acquired a commercial mini-PACS for the echocardiography laboratory (Philips Medical Systems, Best, The Netherlands). Our motivation was its full customization for the echocardiography reporting: it includes some predefined finding codes and measurement macros for cardiac imaging (such as wall motion analysis). This system has been interfaced to our workflow engine to enable a complete workflow cycle: order by clinicians in the EPR, validation by cardiologists, scheduling, image loop acquisition of ultrasounds, report and image review, and transfer to the enterprise PACS (Figure 4). Because the workflow engine tracks all steps, the EPR is automatically notified and the clinician can follow up at any time the examination status within the EPR care plan.

The workflow engine has facilitated the interface between this mini-PACS, PACS, and EPR. The initial computerized workflow was inspired by the traditional paper-based organization: an external order had to be first approved by a cardiologist before any transmission to the ultrasound technologist for scheduling contrary to an internal order that did not require such an approval. After a few weeks of operation, this approval process for external orders appeared to be a bottleneck because of the reminiscence of a paper version beside the paperless workflow. Because of the rare occurrence of external orders, some cardiologists tended not to review their work lists. We finally decided to change the ordering rules to smooth the



**Figure 4.** Architecture used for cardiology (left) and hematology (right).

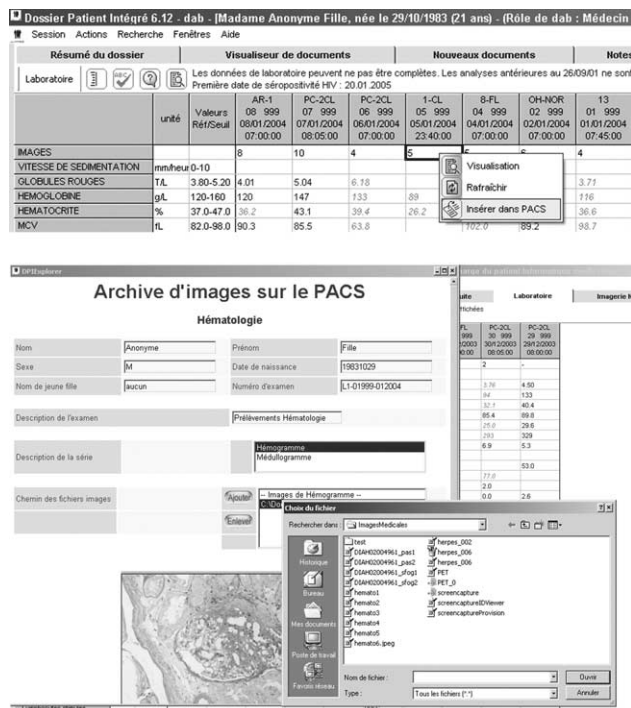
process: external order became both available to cardiologists and the ultrasound technologists, whereas the technician had the possibility to schedule after the cardiologist's oral approval. It is important to note that, using a workflow engine, it was easy to implement this adjustment; in our case, we just had to change the condition rule for the order validation task (Figure 3).

### Hematology

Images are directly stored from the EPR. Hematologists acquire their images from a digital microscope and save them as JPEG files on their local disks. Then they open the target patient record within the EPR and select the appropriate hemogram (graphic record of a differential blood count) (Figure 5). The last step is a simple "paste and copy" file operation from any viewer or explorer to link images to the hemogram. Images are automatically uploaded, converted to DICOM (modality secondary capture) and pushed to the PACS. They finally become available for display through the lab results of the EPR and are associated with the appropriate hemogram.

### Ear, Nose, and Throat

This project aims at storing video laryngoscopies acquired from an endoscope. This endoscope—a charge-coupled device camera—is interfaced to a commercial mini-PACS solution that digitizes and stores videos (Alphatron, Rotterdam, The Netherlands). Because we could not rely on a local scheduling solution, we directly interfaced this product to our hospital information system via HL7 (query and retrieve using the patient's visit identification—Q&R A-19) to get patient demographics. After acquisition, this mini-PACS generates and locally stores JPEG and audio video interleave (AVI), the file format for Microsoft's Video for Windows standard files. After



**Figure 5.** Image upload utility for hematology. This tool is directly available from the lab results (a) and uploads some local JPEG images to the picture archiving and communication systems (b).

the examination has been read, images and videos are then manually exported using our DICOM-XML communication interface detailed previously.

The storage strategy on PACS differs from previous projects because of the huge data volume represented by those videos. For instance, a typical video acquisition may be 3 to 4 minutes long (approximately 200 MB with a frame rate of 25 frames per second, JPEG baseline compressed). Therefore, we decided to support video streaming to improve the video retrieval and visualization. Because DICOM does not yet support streaming capabilities, we chose the MOV file format (Quick Time Movie File Extension), a video and animation system developed by Apple Computer (Cupertino, CA). First, conversion from AVI is simple because the MOV format encapsulates the AVI data. Second, it allows continuous decompression of the data stream progressively transferred via the network. That way, clinician can start to visualize the video immediately after its selection on the PACS.

This implementation combines the following.

- A recent evolution of our PACS, allowing image storage of any file formats. Our supplier released a new

communication interface including web methods to upload and download those non-DICOM files. The file registration within the PACS database is ensured thanks to a unique ID called “document instance UID.”

- Our own implementation to ensure a correspondence between DICOM and non-DICOM worlds. Before the MOV video file is uploaded to PACS, we extract a representative frame from the video loop and convert it as a DICOM file. This image refers to a single DICOM series: this series is labeled “video” within the “series description” DICOM element, and its “series UID” has the same value as the document instance UID used to register the video. As a result, the video is linked to a given series and study within the PACS database. Afterwards, the retrieval process combines both a DICOM query and a web query to consolidate DICOM series and non-DICOM videos.
- An additional viewer used as an alternative to the DICOM Java web viewer. This viewer runs the MOV videos. We elected a free video streaming solution for that purpose (VLC [VideoLAN viewer] <http://www.videolan.org>).

The ear, nose, and throat cancer review board illustrated a successful scenario resulting from this implementation. The enterprise-wide PACS allows a systematic and efficient review of all the cancer cases. An ear, nose, and throat specialist can demonstrate on the videolaryngoscopy the suspect area that can be efficiently correlated to positron emission tomography, MRI, and CT data. He or she can also indicate the exact area of the biopsy. Such relevant information is usually difficult to assess from the written report accompanying the biopsy specimen. Finally, all this visual information is put together and discussed by the specialists.

## DISCUSSION

### PACS Design

An enterprise-PACS could be designed following three different architectures.

- A unique PACS system: this system manages all images produced within the hospital by directly connecting the image producers.
- A hierarchical model coupling multiple mini-PACS to a master PACS: each mini-PACS fulfills the needs of its

specialty and stores the most recent images, whereas the master PACS archives in the long term.

- Multiple PACS systems: each department owns its self-standing PACS. A search engine capable to query all storage units—the portal as named by Ratib (19)—gathers the information pertaining to a patient from the different departments.

The unique system approach is the simplest architecture because it avoids the redundancy of storage and minimizes the integration tasks. However the software complexity introduces a major threat relating to robustness and performance. The second architecture allows flexibility and specialization because each system matches a specific workflow. On the other hand, it burdens the integration and communication. Moreover, it is financially the most expensive as it multiplies the number of systems to be acquired.

So far we have valorized the second approach to pragmatically cope with the heterogeneity of the installed basis in our institution. However, our strategy in the future will be a hybrid of the second and third architectures. We foresee a new architecture based on two enterprise PACS systems: one dedicated to radiology and the second to the other specialties. This distribution based on two systems will help us to balance loads. A search engine has been implemented to query the PACS systems and to give a consolidated view of the imaging records. Because this search engine will be generic, the number of PACS units can be extended if necessary. This solution will be interfaced using a workflow engine to encompass the specificities of medical specialties involved (scheduling, image management, report, and diagnosis). Finally, a unique system will be used to centrally manage the various access rights.

Additionally, we selected the EPR as the main software piece to access the diagnostic images in a unified way. The EPR supplies a generic viewer software able to display all image and videos types. To encompass the various needs, this viewer calls customized processing tools or display protocols via plug-ins.

### Integration Standards

The question arises whether images have to be stored systematically in the DICOM format. DICOM will be the most appropriate format after the two following requirements are fulfilled. First, DICOM should continue to evolve to support the video compression codecs (20) (MPEG, MJPEG) used for endoscopy. Second, lobbying pressure has to be exerted to get suppliers outside radiol-

ogy to effectively support DICOM. In the meantime, a workaround based on DICOM converters can be conceived. A second alternative could be that the enterprise PACS supports DICOM as well as the most frequent multimedia formats (21). The data consistency would be ensured by consolidating the imaging records between the DICOM and non-DICOM worlds. We proposed an implementation in this article for that purpose.

### Challenges in Workflow Analysis

Even if advanced technologies such as workflow engines are available, the key success of an enterprise PACS relies on a deep understanding of the clinical activities and needs. This understanding rests heavily on the quality of the dialogue between the clinical staff and the IT department: it requires a strong partnership and interdisciplinary views to establish the most appropriate work process. This partnership should anticipate the necessary organizational change that new technologies and IT may induce. Moreover, the development of an enterprise PACS should be viewed as a continuous process in which the initial solutions can be further improved. A workflow can be adjusted. Anticipation can be facilitated by the workflow simulation using virtual reality techniques that contribute to a better prediction of the process efficacy and ergonomics for some specialties such as surgery (22). Modesty and a stepwise approach can lead to first successes that will then create a positive dynamic. The right level of expectation should also be set at the beginning of the project. The clinical staff has to be involved and feel accountable for the outcomes.

### CONCLUSION

Our philosophy is to make the best use of the commercially available applications. The workflow engine smoothly integrates those "best of breed" products that exactly match the needs in processing and workflow. The integration of those various applications in a common framework is the added value of our IT department because it allows a tight integration of all clinically pertinent images and video with other clinical information such as reports, laboratory, and order entry in a unified multimedia patient record. We use the radiology PACS as the main storage and the EPR has the common user interface. The policy is to systematically use integration standards and, if that is not possible, to implement temporary solutions. We believe that this pragmatic approach allows

us to answer the needs of the imaging specialties in a timely manner and to help clinicians in their decision process.

The patient-centric EPR is the ideal platform to access the medical records in an exhaustive way and allows a multidisciplinary image review. By unifying the way to access all these data, it eases the use of the patient record and decreases the need for teaching and support. A potential evolution is the possibility to associate any diagnostic images to a medical context (diagnosis, therapy planning, follow-up) and to a predefined workflow stage.

### ACKNOWLEDGMENTS

The authors are grateful to those who performed an outstanding job at developing our enterprise PACS: Andrew Parrott, systems engineer; Michael Dehouck, Lidia Dorsaz, Cyrille Duret, Arnaud Garcia, Frédéric Ribkowsky, Julien Vignali, and Patrice Trolliard, implementation; and Pierre-Alain Mèche and Jorge Remunian, test and evaluation.

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