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MEDICAL IMAGING AND THE INFORMATION HIGHWAY – MOVING TOWARD A "FILMLESS" RADIOLOGY DEPARTMENT

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This paper describes our direct experience in using the Information Highway and associated technologies to manage health care information, specifically medical image data, in a large university health center. Diagnostic imaging has moved toward employing electronic communications and data management to supplant traditional paper and hard copy systems. While much of this can be explained by the increased use of computers in image acquisition and analysis, the emergence of the DICOM standard and the rapid growth of the World-Wide-Web, have allowed this technology to extend beyond simple local area networks. We have focussed on the digital imaging modalities (CT, MRI, ultrasound, and nuclear medicine) and have developed and implemented a picture archive and communications system in-house. Key decisions in our development effort were to make use of the infrastructure provided by the Internet and the resources that are freely available on the World-Wide-Web. In so doing, we developed a Web-based interface to our PACS that has provided an element of telemedicine that has only begun to be explored.

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1. Introduction

This paper describes advances in medical imaging that are leading to the emergence of the fully digital radiology department. While such departments are currently rare, their numbers are growing as the vendors of imaging systems gear their products (almost exclusively) to digital, networked environments. The push to become truly "filmless" comes from many sources: some being financial, while others are clinical and administrative. The transition from an analog (i.e., film) based environment to electronic presents some interesting technical challenges, many of which have been addressed through the development and use of accepted standards. Often overlooked, however, are the needs of users outside the imaging department and low clinical work-flows are affected throughout (and outside) the hospital.

At the Montreal General Hospital, we have taken the uncommon approach of developing our own picture archive and communications system (PACS) to manage the acquisition, archival, retrieval, distribution and viewing of digital image data. The system currently supports three CT scanners, one MRI, nine ultrasound scanners and five gamma cameras, and has allowed us to eliminate all films in these modalities. Our hospital is a 400 bed level 1 trauma centre, and the Department of Diagnostic Radiology conducts approximately 170,000 examinations per year, 40 percent of which are from the filmless modalities above.

1.1 Background

Our PACS began in the ultrasound division in late 1995 and was based upon the existing infrastructure of our departmental Ethernet network. In a short period of time (approximately two methods), we developed and implemented a system that employed Macintosh computers to acquire and view static images, while a Sun workstation maintained a central "Master Database" and coordinated data archival and on recordable compact disks [1]. It immediately became possible to view the images acquired from any ultrasound exam on any networked Macintosh throughout the department, and image retrieval became trivial and fast. The implementation costs were fully recovered in under six months following the elimination of film, and the additional savings were invested in further development that ultimately lead to the re-designed PACS that now manages the other modalities.

The decision to expand the PACS to include CT and MRI came one year after the implementation in ultrasound. This time there was a clear clinical motivation that stemmed from the results of an informal study of "soft-copy" review practices conducted by a group of our radiologists. For a six-month period, the group reported all CT and MRI cases directly from computer screens where they could manipulate image brightness, contrast and perform other image processing operations. A (strong) preference became clear for this method of analysis owing to the belief that it yields a more thorough means of diagnosis, thus greater potential clinical benefit.

It was realized early on that the management of CT and MRI data would present some challenges that had not been faced in ultrasound. The two most significant were the need for more sophisticated image analysis software (for diagnostic review) and the need to provide users outside of our department with access to the images for clinical review purposes. Given the larger population to be impacted and the greater volumes of data to be handled, it became clear that a more robust and scalable PACS was required. Thus, we designed a new system using a mix of concepts that had proven to be successful in ultrasound and others that addressed the issues mentioned above. Key decision along the way were to follow the digital imaging and communications in medicine (DICOM) standard and to employ a distributed design comprising specialized servers, each running the *LINUX* operating system on IBM PC - compatible computers. While the latter choice also satisfied our need to minimize development costs, it was in no way a compromise in selecting a robust and flexible operating system and platform.

1.2 Dicom

The current version of DICOM (3.0) was released in 1993 by the National Electrical Manufacturers Association (NEMA) in collaboration with the American College of Radiology (ACR). The ACR and NEMA had published two earlier versions, but neither had gained a significant level of support from commercial vendors to achieve the primary goal of facilitating the exchange of digital images and related information (transparently) between any two networked computers. Version 3.0, which addresses the issue of information exchange over computer networks, is now widely embraced by commercial vendors, marking it the de facto standard in medical imaging.

By adhering to DICOM in developing our new PAC, we ensured that it would easily accommodate any future imaging equipment that may be added, and we facilitated the process of exchanging data with others. This, in turn, provided the assurances that our investments would avoid premature obsolescence and allow the system to easily be shared with our sister hospitals that are part of McGill University.

1.3 The role of the Internet

The design to implemented a PACS and MRI to support soft-copy viewing and management of digital image data was counter-balanced by financial pressures, making this new technology difficult to justify without saving being generated elsewhere. Given the relatively high number of these examinations performed in our department, we believed that the elimination of films would provide a significant source of funding to offset development and equipment costs. One key decision that helped to minimize costs was to employ the infrastructure offered by the Internet as a means of providing outside users with access to images residing on our PACS. The financial motivation underlying this decision reinforced the primary reason; namely, that these existed no other practical means of providing image access to such a wide population of users. From the technical standpoint, the choice to develop a World-Wide-Web (WWW) browser-based interface to our PACS, again, seemed obvious. The client-server model fit our paradigm perfectly, and platform independence of the approach obviated the need to develop software for each specific type of personal computer. Furthermore, we believed that the rapid growth in the population of WWW users would contribute to the acceptance of our system and help to minimize user training.

We describe the PACS in more detail in the following sections, emphasizing its Web-based components. The PACS continues to evolve with the Internet playing a key role in helping us to overcome geographical limitations and provide more timely service s without the use of film. Below, we also describe the potential use of the Internet for teleradiology.

2. Materials and methods

2.1 Software Choices

In re-designing the PACS to support CT and MRI (and later medicine), we anticipated the need for a more robust operating system than had been employed in ultrasound. Our preference for UNIX leads us to adopt the LINUX operating system (a variant of UNIX) which had the dual benefit of being freely available (from the public domain) and being based on the Intel CPU which, arguably, has the best price-to-performance ratio in the industry. In fact, this decision to employ freely available software was repeated often as we gathered the elements needed to develop each component of the new PACS.

Coincidentally, we found the most robust and fully developed implementation of the DICOM standard to be freely available on the WWW [2]. The implementation was developed by the Mallinckrodt Institute of Radiology whom were commissioned by the Radiological Society of North America (RSNA) in 1993 to develop a suite of software, comprising a *Central Test Node* (CTN), to serve as a test-bed for commercial vendors to demonstrate the DICOM conformance of their equipment at the 1993 RSNA meeting. This software was written in C to run specifically on UNIX-based systems (see http://www.erl.wustl.edu/DICOM/ctn.html). With relatively few changes, we were able to compile and run the CTN software under *LINUX.*

Our choice of a database for the PACS was largely dictated by the choice to employ the CTN software which supported one freely licenced database called mini-SQL [3] (see: http://www.Hughes.com.au/) and one commercial database (Sybase). We chose the former which, like the CTN software, was written in C.

For developed purposes, we have employed gnu C/C++ and the Perl scripting language, and many other gnu utilities, all of which are available from the Free Software Foundation (see: http://www.fsf.org/home.html). In developing the PACS, we extensively modified the CTN software and have employed mini SQL to support many new applications peripheral to the PACS. These modifications are beyond the scope of this paper, but they have been necessary to make the software more robust and to support a multi-server, distributed design that includes near-line and term archival and retrieval.

2.2 New PACS Architecture

The resulting re-designed PACS comprises multiple "servers", each dedicated to specific functions. Each server is described below in the context of image-flow.

2.2.1 Modality Server

As images are acquired on a given scanner, they are transmitted automatically to a specific Modality Server for storage on a redundant array of inexpensive disks (RAID). The Modality Server then transmits copies of the images to various destinations based on pre-defined routing-rules. Destinations include diagnostic review workstations (used by radiologists), clinical review workstations (used by Hospital clinicians), and the Archival Servers (described below). The routing-rules can depend on many different parameters related to the study being performed, including the imaging modality and the type of study being performed. Many other parameters may be used as well, including the name of the referring physician; day of week; time of day; scanner name and patient name.

Each Modality Server also performs automatic "prefetching" of prior studies, when they exist. As the first image of a new study is received, the Modality Server consults the Master Database, which resides on the Database Server (described below), to see if the patient has had any prior relevant studies. If so, those studies will be retrieved (if necessary) then routed automatically to the same destination(s) as the images in the current study. Having prior relevant studies available facilitates the task of making diagnostic comparisons.

Image transmissions to and from each Modality Server, and every other Server in the PACS, conform to the DICOM standard. One Modality Server is employed per imaging modality (CT, MRI, ultrasound and nuclear medicine). Each Modality Server also acts as a fully-capable WWW server and provides WWW access to the images on its RAID. This function is described below greater detail.

2.2.2 Archive Server

The new PACS has two Archive Servers; one that employs recordable CD technology, and one that employs a digital linear tape (DLT) juke-box. As images are received from each Modality Server, they are grouped by series then recorded automatically to CD and DLT for long-term storage. The tapes remain within the juke-box but the CDs are labeled and delivered to the film filing-room where they are stored in a cabinet.

2.2.3 Retrieval Server

When images are required that are no longer available on many Modality Server, they are retrieved from DLT or Cd. Retrieval requests are issued automatically (either from a Modality Server or from the WWW Server (described below)) when off-line data are accessed. Retrieval from the DLT juke-box is automated and is employed whenever possible; in preference to retrieval from CD. Retrieval from CD requires human-intervention and is performed by the film filing-room staff who are alerted by an audible signal on the CD Retrieval Server that is located next to the CD storage cabinet.

2.2.4 Database Server

A "Master Database" tracks the images comprising every study handled by the PACS. This database (based on mini-SQL) resides on a dedicated Server and receives input from every other Server in the PACS. It keeps track of all patients, studies and series, including their location(s) (e.g., whether they are on CD, DLT, Modality Server, or a Retrieval Server). The database is queried by every Server and is presently the only centralized component in the PACS.

2.2.5 Diagnostic Workstation

In a filmless department, the diagnostic workstations are analogous to film light-boxes and multi-viewers. They are used by the radiologists for primary diagnostic reporting. In our case, we lacked the resources to develop our own image analysis software, so we opted for a commercial solution. The resulting workstations are UNIX-based dual monitor systems with sophisticated software and features designed for the analysis of tomographic image data (including 3-D image processing tools). Each supports the DICOM Storage Service Class as a User and Provider, and the Query-Retrieve Service Class as a User. Thus, the radiologists are able to query any Modality Server and "push" or "pull" images to and from it.

2.2.6 WWW Server

Our WWW Server supports our "PACS-browser" software which was initially developed to run on a dedicated computer (under *LINUX*) employing the Apache Web Server [4]. Each Modality Server was configured to automatically forward a copy of every image received to the WWW Server to make it available for viewing outside our department. This process employed the DICOM standard with the WWW Server acting a Provider of the Storage Service Class and the transmitting server acting as the User. Each incoming image was stored on the local hard disk in DICOM format and a copy was converted to a JPEG format. A local database residing on the WWW Server kept track of the images received.

Perl and HTML pages were constructed to provide access to the images. The use of Java was intentionally avoided owing to concerns the most PCs were inadequately equipped to support it. In order to maintain the confidentiality of patients, each user was required to apply for an account that was enabled after their identity had been verified. Usernames and encrypted passwords were employed in addition to an underlying system that restricted different users to specific functions depending on their role within our institution and depending on the location from which they logged-in.

The range of functions designed within the PACS-browser included the ability to view images; print images (only on paper); move images (full studies or series) to any DICOM-capable workstation known to the PACS; download images in DICOM format, or prefetch studies. Fig. 1 illustrates the PACS-browser being used for image viewing.

Management of disk space on the WWW Server was automated using a first-in-first-out policy with high and low water marks. As data were deleted from disk, the local database was updated to reflect the changes. Initially, four 9GB hard disks were employed which was sufficient to hold approximately three weeks of the most recently acquired images. When older images were required, it was necessary to re-transfer them to the WWW Server from either a Modality Server (if the data were still on-line) or a Retrieval Server.

The initial design and development of the PACS-browser took one man-month before being implemented. The subsequent elimination of films in CT and MRI (in February 1997) produced a significant dependence on the PACS-browser that brought to light various deficiencies. The most important of these was related to image quality which suffered from poorly selected window widths and levels being used to generate the JPEG versions of each image. This was rapidly addressed and also resolved similar issues with images being printed on paper. Several enhancements to the interface were also made over the first few months including the addition of more sophisticated database query tools and simple image manipulation controls.

As the user population grew and the volume of data managed by the PACS accumulated, concerns were expressed that image access times were suboptimal. In order to facilitate an investigation into these concerns, we conducted an analysis of the datavolumes being handled on the network along with image transfer speeds [5]. The results showed a high percentage of data older than three weeks being accessed primarily via the WWW Server. This meant that users of the WWW Server who needed these data were required to wait while the data were transferred (either from a Modality Server, or a Retrieval Server) to the WWW Server and converted into JPEG format for viewing. This process also meant that there was a high degree of network traffic directed to the WWW Server and that its CPU was computationally burdened with the overhead of DICOM communications and file format conversions.

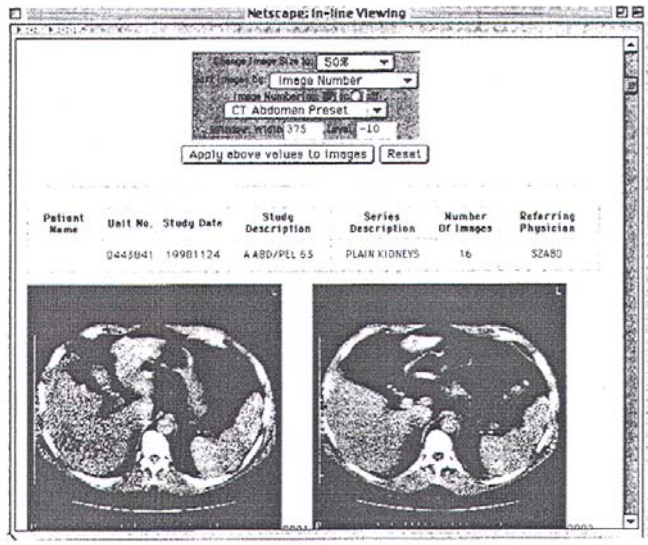

Fig. 1 Images are able to be viewed on the WWW using MGH PACS-browser.

At first, we were tempted to increase the storage capacity of the WWW Server by adding hard disks, but we realized that this would not resolve the issues of network and computational loads. Since the image data were distributed across multiple Servers (i.e., on the RAIDs of the Modality Servers), we realized that it would be far more efficient to "transfer the user to the data" rather than transfer the data to the user. This was achieved simply by equipping each Modality Server (and Retrieval Server) with a fully functional copy of the PACS-browser software (after minor modifications) and having JPEG images generated for every DICOM image received (or retrieved). This provided instant WWW access to all images on the RAID of each Modality Server.

The advantages of this change include immediate access to any on-line image on the PACS and a more equitable distribution of computational load across the PACS Servers. It also allowed the three weeks of storage provided by the four 9GB disks on the Web Server to be increased to over four months. In fact, once three of the 9GB disks were reallocated to the Modality Servers (since they were no longer required on the Web Server), this increased to nearly five months. A large reduction of network traffic was also achieved and the single point of failure that was previously inherent in the design was eliminated. Ultimately, this modification has allowed us to improve the service our PACS provides.

Table 1 summarizes the roles of each Server in the PACS.

Table 1 Summary of departmental PACS Servers and their functional roles

Modality Server	- 1 for each scanner - DICOM Storage SCU/SCP - Query/Retrive SCP	- receives images from scanner - provides storage on RAID - auto-routes images to appropriate destinations - auto-prefetches - services queries and retrievals - receives images from workstations - services print requests (paper) - provides WWW image viewing
Archieval Server	- 2 for department 1 CD-R system; 1 DLT juke-box - DICOM Storage SCP	- receives from Modality Servers - records data on CD and DLT
Retrieval Server	- 2 for department 1 for CDs; 1 DLT juke-box[1] - DICOM Storage SCU	- restores images from CD or DLT for distribution to other destinations - services print requests (paper) - provides WWW image viewing
Database Server	- 1 for department - no DICOM functions	- maintains "Master Database" - keeps track of all studies performed - knows location of any study/series eg, on-line, off-line (CD/DLT)
WWW Server	- 1 for department - DICOM Storage SCP	- provides WWW access to all images - ability to search Master Database - coordinates image viewing, downloading, moving, searching, printing, and much more

3. Results and discussion

Although used primarily from within our institution, PACS-browser has also allowed us to extend the services of our department to users on the Internet. In anticipating this, we were careful to provide the means for users (eg, referring physicians) to easily obtain access after having obtained the appropriate level of authorization. Extensive logging is used throughout the system which facilitates the process of conducting audits and helps with general trouble-shooting.

A drawback to our scheme of distributing WWW access across our Modality Servers is the difficulty of employing such an approach in conjuction with a firewall. Providing access to each Modality server would require several points of access through the firewall which could increase vulnerability and be difficult to manage. Since a firewall will soon be installed at our institution, we will likely employ a single WWW Server outside the firewall that would receive images from the PACS in a fashion similar to our original design, albeit only when necessary. Since there are many fewer users outside the Hospital, we expect this approach will easily handle the loads.

Our use of the Internet and the decision to provide a Web-based interface to our PACS has served us well. In fact, we have employed the same approach to solve several additional problems. The need to create and catalogue radiological teaching files in a filmless environment became apparent soon after the PACS was launched and films were no longer available in CT and MRI. A new Server dedicated to maintaining a database of electronic teaching files, comprising images and text, was developed using the same approach employed to develop the PACS-browser [6]. The resulting system is now tightly integrated with our PACS, allowing authorized users (primarily radiologists and residents) to easily create teaching files. A major attraction of this new system is that the files become immediately accessible throughout the world by virtue of being on the Internet (see: http://tf.rad.mgh.mcgill.ca/).

As the PACS continues to grow, support and maintenance has increased in complexity. To address this issue, we have developed a suite of Web-based PACS management tools. The resulting tools allow our PACS Administrator to add new users; define new DICOM application entities: setup image routing rules; control defaults for preset JPEG window widths and levels; monitor DICOM image transfer queues, network connections and processes running on each Server. This has greatly facilitated the task of managing the PACS, even allowing it to be done remotely.

Most recently we have developed an interface between our PACS and hospital information system (HIS). Our goal was to link images residing on the PACS with their corresponding reports. The interface, however, is limited to receiving orders for radiology exams from the HIS and returning the reports (to the HIS) after being transcribed. Previously, each report was transcribed directly into the HIS making it inaccessible to the PACS, so we developed a new Web-based application that allows the reports to be transcribed on the PACS side while a copy is sent to the HIS. The local copy is now linked to the corresponding images on the PACS and is accessed through the same PACS-browser application that is used to view images. Developing a Web-based transcription application has allowed the existing computers in our department (a mix of Macintosh and IBM PC-compatibles) to be used and has grown to include an application that is now used by our radiologists to perform corrections electronically (see Fig. 2). The latter can be used from anywhere on the Internet given adequate security. This has increased the efficiency of the reporting process and reduced turn-around times significantly.

The distributed WWW Server architecture now employed in our PACS is analogous to the World-Wide-Web itself. Rather than try to centralize the storage and access to all information, it is distributed and linked over the Internet, allowing the collective resources to be shared without any complexity from the user's point of view.

The use of the Internet and our PACS-browser to provide access to digital images on our PACS has clearly been successful. We have managed entirely without films in CT and MRI for almost two years now, and for over three years in ultrasound. Despite some initial difficulties related to image quality, the system has provided a new model for image delivery within our institution that has recently expanded to include images from nuclear medicine and, soon, computed and digital radiography.

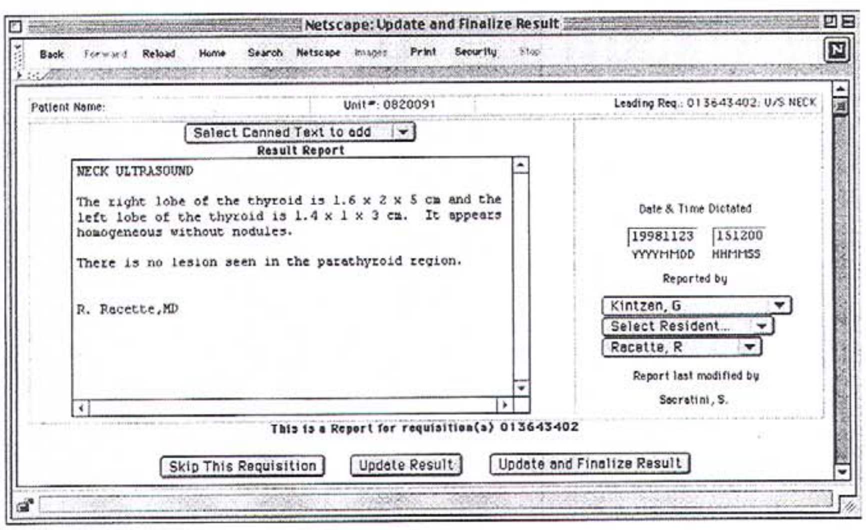

Fig. 2 Radiology reports are now transcribed and verified electronically via the MGH PACS-browser. This has minimized wasted paper and is expected to shorten the overall reporting cycle. Images for each report are able to be viewed through the PACS-browser as well.

This model puts greater control of image access into the hands of users. Unfortunately, when one is used to physically handling and carrying films, seeking a networked computer to access images is seen as inconvenient. The challenges to address this issue are largely financial and matter of changing attitudes. The benefits, however, are undeniable: Electronic images do not get lost and allow multiple users access at the same time. Given Internet access, images can be shared world-wide in a matter of minutes and at almost no cost. This clearly illustrates that there exists the potential for Internet-based teleradiology.

4. Conclusions

Our experience in digital imaging and PACS has been very positive and we are pursuing extensions of this technology into the area of conventional radiography. The Internet and World-Wide-Web have provided us with the means to adopt PACS-related technologies and implement them affordably and effectively in our institution.

The potential for new uses of this technology is clear. Telemedicine and teleradiology are two excellent. But there are still several technical hurdles that include how to ensure network bandwidth and respect for patient confidentiality. The former is particularly challenging in the field of radiology where the data volumes are among the highest of all medical specialties. Here, gigabit Ethernet and ATM seem to offer promising solutions. Privacy of information on public networks is being addressed through the use of encryption techniques, but their use is still limited and hampered by the lack of agreed upon standards. In some areas, private networks have been proposed and are being developed to address these issues. Thus, the future role of the Information Highway in health care is uncertain, but its influence has been undeniable.

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