Performance and Function of a Desktop Viewer at Mayo Clinic Scottsdale

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A clinical viewing system was integrated with the Mayo Clinic Scottsdale picture archiving and communication system (PACS) for providing images and the report as part of the electronic medical record (EMR). Key attributes of the viewer include a single user log-on, an integrated patient centric EMR image access for all ordered examinations, prefetching of the most recent prior examination of the same modality, and the ability to provide comparison of current and past exams at the same time on the display. Other functions included preset windows, measurement tools, and multiformat display. Images for the prior 12 months are stored on the clinical server and are viewable in less than a second. Images available on the desktop include all computed radiography (CR), chest, magnetic resonance images (MRI), computed tomography (CT), ultrasound (U/S), nuclear, angiographic, gastrointestinal (GI) digital spots, and portable C-arm digital spots. Ad hoc queries of examinations from PACS are possible for those patients whose image may not be on the clinical server, but whose images reside on the PACS archive (10TB). Clinician satisfaction was reported to be high, especially for those staff heavily dependent on timely access to images, as well as those having heavy film usage. The desktop viewer is used for resident access to images. It is also useful for teaching conferences with large-screen projection without film. We report on the measurements of functionality, reliability, and speed of image display with this application.

WE REPORT ON THE function and performance of a desktop viewer[1] installed at Mayo Clinic Scottsdale. While our hospital has been filmless since May 1999,[2] the outpatient clinic has continued to print films (Radiology is soft copy) due to the incomplete deployment of a desktop viewer for clinical and specialist imaging. Providing a robust, highly reliable, and user-friendly desktop application viewer is essential for the electronic practice to meet the goal of increasing clinician efficiency and reducing costs. The desktop viewer we deployed was developed and has been in use at Mayo Clinic Rochester (8,500 desktops have it installed) since 1997.[3,4] The implementation of the viewer (QREADS) is mission-critical to the goal of film reduction. Approximately 50 copies of QREADS have been installed at this time. QREADS resides as an application on the desktop along with the suite of other applications forming our electronic medical record (EMR).

FUNCTIONAL OVERVIEW OF THE CLINICAL IMAGING NETWORK

Figure 1 gives an overview of the network. At the desktop, the clinical sign on (CSO) toolbar gives physician access to the profiled secure environment. Client applications available are the patient's electronic record (IDX Corp, Burlington, VT) and QREADS. Once the physician has signed on, a desktop icon provides access to QREADS. Launching QREADS and selecting the "patient ID" box will automatically transfer the correct patient information from IDX to QREADS. Mayo's radiology image management system (RIMS)[5] will immediately send a list of all examinations, and QREADS will display the report on the currently selected exam. Should the physician wish to actually view images, double-clicking the examination satisfies this request. QREADS then reads the image files from the clinical image server (CIS), an NT (Microsoft, Bellingham, WA) server that contains approximately 1 year of images (200 Gbyte) in compressed form. Network protocol is Transmission control Protocol/Internet Protocol (TCP/IP) with 10/100 Base T.

The imaging network is designed to get all examinations (reports and images) to the physician staff as quickly as possible. Upon examination completion, RIMS issues a Digital Imaging Communications in Medicine (DICOM) CMOVE command, transferring images from the picture archiving and communication system (PACS) source, either GEMS (General Electric Medical Systems, Milwaukee, WI) E-View PACS 8.0 or ALI Technologies (Vancouver, Canada) 3.0, to the Clinical Images Gateway (CIG). The CIG is an NT workstation that receives the examination via the PACS DICOM Gateway (DGW) and verifies the proper

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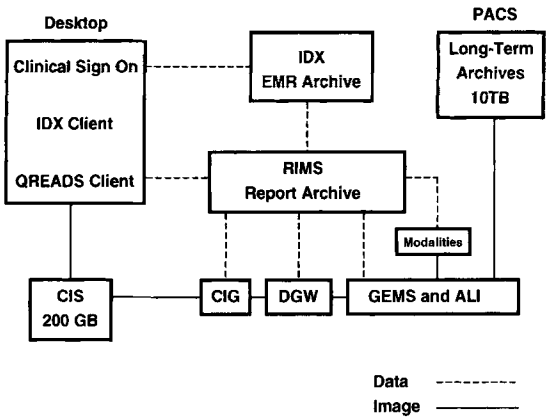

Fig 1. Overview of the integration of QREADS, IDX, RIMS, and PACS.

image count using RIMS. The CIG is currently configured to perform decimation on computed radiography (CR) images (to 1K × 1K × 8 bits), as well as a modality-specific wavelet or JPEG compression.[6,7] Images are stored in compressed form until needed on the CIS. They are transferred in this format and decompression occurs at the workstation upon display (ie, they are stored in workstation memory as compressed files). The CIG uses DICOM elements (accession, study, and series numbers, image count, series instance unique ID, pixel calibration, and modality type)[8] to accomplish its tasks of insuring complete examinations and providing necessary information to the QREADS client. Thus, all of the modalities sent to PACS are required (and prequalified) to provide these DICOM elements. Preset windows are established by modality and the image count is used to map real estate on the viewer. We actually use four CIGs: three for the GEMS PACS and one for the ALI PACS to enhance performance. CSO, CIS, CIG, RIMS, QREADS application, and the wavelet compression algorithm[9] are Mayo-developed systems. The imaging modalities available to physicians and their compression values are given in Table 1. The numbers in parenthesis indicate multiples of this unit.

PHYSICIAN AD HOC AND PREFETCH OF IMAGES

It may be desirable to view prior examinations (reports and images) even if *no* order is being made for radiological services. If an examination is not on the CIS for any reason, the physician can initiate an ad hoc fetch from PACS. The images will be fetched regardless of their location (short- or long-term storage).

In the event that the physician orders a *new* radiological examination, the request is passed to RIMS, which initiates a DICOM CMOVE from PACS (both long- and short-term archives) to the CIS. (This same event also causes a prefetch from long-term archive to short term archive of all exams of the same body part as part of our PACS prefetch scheme). Thus current and prior examinations of the same procedure code are quickly available. We report on the performance of these

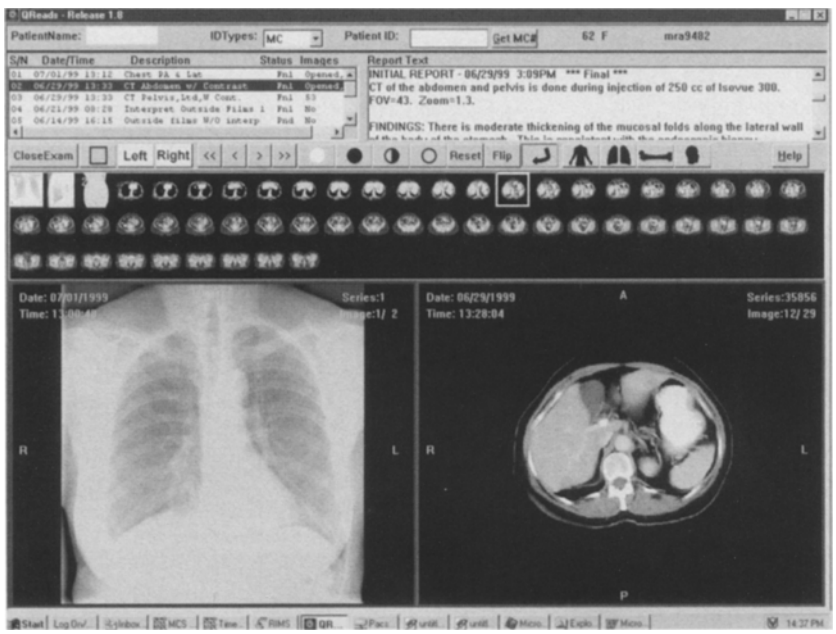

Fig 2. Display application for QREADS. Upper left is listing of all patient exams. Note 2 exams are open. The report for the selected exam is displayed on the upper right. Small snapshots of all images are given, with the PA chest and CT being viewed. Double clicking on any image will give full screen access to the image. Viewer is coupled with the patient's ID.

Table 1. Modalities and Compression Used With Desktop Viewing

Modality	Vendor	Image Compression
Thoravision (×2)	Philips	20:1 wavelet
CR (×11)	Fuji/Analogic CRQA	20:1 wavelet
CT	Marconi Twin Flash	10:1 wavelet
CT (×3)	Siemens Somatom +4	10:1 wavelet
CT	Siemens Volume Zoom	10:1 wavelet
MRI (×3)	GEMS LX	5:1 wavelet
MRI	Philips Gyroscan	5:1 wavelet
U/S (×8)	Acuson	10:1 JPEG
U/S (×2)	B + K	10:1 JPEG
U/S	GE	10:1 JPEG
U/S	ATL	10:1 JPEG
Angio Digital Spot	Siemens (Multistar TOP)	20:1 wavelet
Angio Digital Spot	Philips (MD4)	20:1 wavelet
Urology (Digital spot) (×2)	Liebel/Flarsheim	20:1 wavelet
C-Arm Digital Spot (×5)	OEC AAM box/native	20:1 wavelet
R/F Digital Spot (×3)	Siemens Sierskop TOP	20:1 wavelet
Nuclear Gamma Camera (×4)	ADAC	20:1 wavelet
R/F Digital Spot—ERCP	Infirmed on Philips Classic	20:1 wavelet

requests, for both the Clinic and the Hospital, as they are separated by 25 kilometers. Timely availability of the radiological examination, reports, and images are very much the essence of the usability and satisfaction of the physician staff.

QREADS DESKTOP VIEWER APPLICATION

The QREADS application provides thumbnail images of the examination, as well as a "two-on-one" default display. The user can select images from the thumbnail to view any image in the default real estate. Double clicking on one image will present the user with a full-screen display. Window/level (W/L) are applied to the current image or series by pressing corresponding buttons (brightness, contrast). For computed tomography (CT) scans, preset W/L settings for bone, soft tissue, lung, and brain are provided. The list of examinations and the report for the selected examination are always displayed. Flip, rotate, distance measurements (mm), angle, zoom, and cine review are some of the tools provided the user. It is possible to compare exams (reports and images) on a patient. Scan plan images for magnetic resonance images (MRI) (both vendors) and Scout view images from CT (Siemens, Erlangen, Germany) are viewable in QREADS, as are three-dimensional reconstruction and maximum intensity projection (MIP) images. QREADS is also used for staff and resident conferences, as it eliminates dependency on the use of film, as well as being available in staff offices for general use. This application has been incorporated into the conference room projection system for group viewing.

QREADS MONITORING AND SUPPORT TOOLS

Upgrades

QREADS is one of the suite of applications included in our standard clinical desktop. Updates to QREADS are currently performed using a product from Microsoft (system management server), but QREADS has been deployed in Rochester using its auto update feature. With this feature, QREADS checks its date versus a version that is on a central server, and if it is not current, it will auto update this workstation with the more current version.

Usage Monitoring

As reported, QREADS provides comprehensive monitoring tools to identify utilization and viewer preferences.[3] W/L adjustments, and staff preferences for viewing just the report or both the report and images, or just the images can be quantified. These tools allow for the accommodation of workload and customization of the viewer application.

Graphical User Interface for Gateway Administration

Since performance is judged to be very highly correlated with physician and patient satisfaction, additional performance-enhancing tools were developed to insure image availability on the CIS. The four CIGs (each of which is configured to handle 10 associations) are provided with intelligence so that when any one CIG becomes overloaded, it will automatically move the next transaction request to the next CIG. If that one is busy, it moves the request to the next one. Further, a graphical user interface has been developed that permits an administrative reassignment of the normal one to one DGW-CIG pairing to allow any configuration. Any combination of DGWs can be assigned to any combination of CIGs. This is particularly useful during periods of outages, testing, or routine maintenance.

METHOD OF TESTING OF QREADS

We judged the quality of service in three important areas.

Functionality

What tools and/or functions are missing that are needed to satisfy the clinical review of images? The test of functionality was performed during a pilot test of deployed QREADS to three departments (Hematology, Cardiology, and Endocrinology). Feedback from the staff was performed through a series of meetings and a questionnaire. The pilot lasted for 3 months, after which QREADS migrated into production.

Reliability

What is the certainty that any requested examination is available to the clinician? The test of the reliability of the service was performed using the monitoring tool and the database of calls to the help desk. A total of 10,000 historical examinations were batch-requested from PACS, and the number of times the exam was available at the CIS was recorded. This batch request was necessary to backload the server with historical examinations to provide a reasonable likelihood that the clinically requested exam would be available. Further, during the pilot the number of times that the exam to be viewed was requested at the desktop and *not* available was recorded in the help desk database.

Speed

How long does it take to display a requested examination? Testing was performed using our standard suite of examinations[2] given in Table 2. Since patient identification and reports reside on a server in Mayo Clinic Rochester,[5] we (Scottsdale) included their display times as part of the performance testing. The CIS for QREADS resides locally at the Mayo Clinic Scottsdale, a distance of 20 kilometers from the Hospital. We tested the speed of examination transfer using 10 examinations for each modality at both locations for:

1. Time to view the report.
2. Time to view at the desktop, following physician selection of an examination.
3. Time of arrival at the CIS of an exam that is finalized in RIMS.
4. Time to view at the desktop—ad hoc request from PACS short-term storage.
5. Time to view at the desktop—ad hoc request from PACS long-term storage.

A standard examination and image size for Thoravision, CR, CT, and MRI (our standard test suite) was used in these measurements. For purposes of measurement, the time to be "viewable" was taken as the arrival of the first image in an exam.

RESULTS

Functionality

A 100% (9/9) overall satisfaction rate was reported by the clinicians involved in the pilot. However, specific requests to improve QREADS usage were identified as follows: (1) nuclear examinations (bone and thyroid exams) were not available in QREADS during the pilot; (2) CT lung images were not of comparable quality to that provided to other CT body parts; (3) distance measurements performed on the image gave numbers that overlaid the structure of interest; and (4) it was found possible to launch multiple copies of QREADS from the client CSO toolbar and cause the desktop to lock-up.

Table 2. Performance Measurements of a Desktop Viewer

Variable	Function/ Platform	CR (1 exam with 2 Images—8.5 Mbyte image size)	CT (1 exam with 50 images—529 Kbyte image size) 3 Series/Exam	MR (1 exam with 144 images—132 Kbyte image size) 5 Series/Exam
Time to view the report	View report at the desktop	<1	<1	<1
Time of arrival of the first image from the CIS	View images—desktop	<4	<1	<1
Time of arrival at the CIS following Completion in PACS	Transfer of images—CIS	50	60	120
Time of arrival at the Desktop—ad hoc-requested from PACS short term	View images—desktop	120	120	300
Time of arrival at the Desktop for an exam that is ad hoc-requested from PACS long-term storage	View images—desktop	600	600	900

Reliability

All of the 10,000 historical examinations requested from PACS did transfer and were available at the CIS for the clinician. Measurements of clinical usage during the pilot showed that approximately 1,500 requests for viewing were made over a 3-month period. The first month measured examination availability at approximately 93%, while the last 2 months measured it at approximately 97%. The current month of statistics (December 1999) shows one occurrence of unavailability out of approximately 500 requests (~99.99%).

Speed

The results of the testing for speed of display are given in Table 2. Values are the amount of time (seconds) for nine of 10 of the exams to be viewed.

DISCUSSION

Functionality

Function of the clinical imaging network was judged quite favorably. Clinicians felt the immediate availability of images and reports to be an enhancement to their practice. QREADS, while written in C++ and while it is available from within a browser, is not a web application. The dedicated application allows functionality that is not currently offered with commercial web applications. In particular, availability of images "at the desktop" immediately upon request provides high satisfaction for the end user. Similar to other authors, image quality was judged to be less than that of film or that available at a PACS high-resolution, high-brightness monitor display.[10-13] Clinical viewing was performed using color cathode ray tube (CRT) monitors (17″ or 19″ Sony [Park Ridge, NJ] Trinitron) or color active matrix liquid crystal displays (NEC [Itasca, IL] 18″ or 20″).[14] Standard clinical desktop resolution is 1,024 × 760 for all units, except the NEC 20″, which are 1,280 × 1,024. Some physician users (orthopedic surgeons and pulmonologists, who viewed images using QREADS, but who were not official participants the pilot) expressed a need for image quality that is higher than that usually provided with a standard PC monitor. We are addressing this need through the selection of improved display capabilities for those users. CT lung images were found to be particularly sensitive to both the type and ratio of compression applied in use. We have reduced the compression ratio for CT examinations and have noted the improved clinical review quality as a consequence. Further improvements are under development and include the use of greater bit depth and the use of JPEG 2000 compliant compression.[15] While JPEG 2000 will likely not require support of 16 bit pixels, the use of high-bit depth data sets are in compliance with the standard. More work needs to be performed in the area of data compression. In our environment, one compression scheme (lossless) is used for wide area network transfer, another is used for workstation display, and another is used for long-term archive. It is compelling, at least from a systems approach, to consider compression to be performed at the modality and to allow decompression to take place as needed. The elimination of redundant occurrences of number crunching would be advantageous, as well as providing savings in archive space.

Reliability

We found three reasons for examinations not being available in QREADS. First, not all examinations are being sent to PACS at this time. This includes bone mineral analysis, one gamma camera, one radiographic-fluoroscopic room, color Doppler ultrasound examinations, and the images/screens produced for CT calcium scoring. One room (endoscopic retrograde cholangiopancreatography) was added during the pilot. Applications such as functional MRI (fMRI) and nuclear cardiology bulls-eye and quantification software that is modality-specific are not sent to PACS and therefore are not available in QREADS.

A second reason certain images were not available during the pilot was if the request was for an unloaded historical examination. The historical loading necessitated an archive prefetch from PACS to the CIS for exams of the previous 9 months. This prefetch contended with the normal prefetch and exam archive in production PACS, and thus took longer than anticipated. By the end of the pilot, all examinations from the previous 9 months were on the CIS. The initial low availability rate measured (93%) during the pilot primarily occurred as a consequence of these two reasons.

The third cause of images not being available is component failures. Lock-ups occurred on the DGW, the CIG, and the CIS. As these problems were resolved, the reliability of the service has improved to that which we enjoy today (~99.99%).

Speed

The speed with which the report and images can be viewed are of major significance to the overall acceptance and satisfaction of the clinical staff. The standard of comparison is *not* the speed with which film could be made available, but the speed with which the images can be viewed on the screen. High acceptance levels by the clinicians were very much the result of the speed with which the exam could be viewed by the staff as well as shown to the patient.

Time to view the report. The report was viewable in less than 1 second, even though the report is archived in Minnesota.

Time to view the first image from the CIS. The time to view the first image (9/10 exams) was 4 seconds for CR and 1 second for CT or MRI when the images were available on the clinical server. The longer display times for CR are related to the larger image file size. It may be noted that this time is identical to the specification we have measured for Radiology PACS for CR exams. For CT and MRI examinations, QREADS and PACS display times are comparable.[2]

Time of arrival at the CIS following completion in RIMS. CR and CT exams typically were available in 1 minute, and MRI exams in 2 minutes following completion in PACS. The availability of the images to the clinician is enormously improved over film, and can be made available in most instances prior to the patient leaving the radiology department.

Time to view images from short-term or long-term archive. A prefetch of an examination to the CIS occurs automatically if the patient has a newly ordered exam. The measured times (2 to 4 minutes and 8 to 10 minutes) for short- and long-term archive retrievals do not pose a problem, since they occur immediately upon the exam order, and before the patient actually has the new exam. Since many patients return for annual examinations, the new orders being placed trigger a request that will not actually be used for some time. It appears reasonable to extend the CIS archive to approximately 12+ months to provide greater reliability of exams being present. Our experience with ad hoc requests for examinations older than 9 months for patients not having radiological examinations is limited at this time.

CONCLUSIONS

A PC desktop viewer has been installed and shown to have a high degree of clinical acceptance in a filmless environment. The high level of function, reliability, and speed of the desktop sever are essential in the overall acceptance and satisfaction by the clinical users.

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