PACS and Teleradiology in the Department of Defense

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Abstract
The U.S. military through the Medical Diagnostic Imaging Support (MDIS) system is installing Picture Archival Communications Systems (PACS) and teleradiology at multiple medical treatment facilities throughout the US and abroad. The goals are to improve patient care, maximize limited resources, and realize cost savings. This presentation reviews early experience with clinical use of the MDIS PACS and teleradiology configurations. Emphasis is on lessons learned in the areas of image quality, speed of image transmission, communication between sites, and the advantages of the MDIS two-way teleradiology configuration. The data is accumulated from the combined experience of the authors at multiple sites within the continental US and Korea.

1. Introduction
The technology for Picture Archiving and Communications Systems (PACS) and teleradiology has been under development for many years, but implementation in the clinical environment has been a slow process. Advances in computer technology, display technology, digital storage media, and network technology, have made PACS and teleradiology both more affordable and more clinically useful. Cost and system performance are still the limiting factors, but these can be expected to improve over the next several years.

The Medical Diagnostic Imaging Support (MDIS) system, being implemented through the Medical Advanced Technology Management Office (MATMO) at Ft. Detrick in Frederick MD, is a large Department of Defense (DoD) project implementing PACS and teleradiology at numerous military medical treatment facilities in the U.S. and overseas using a network of computer-based digital devices that electronically manage diagnostic images within a medical treatment facility and associated clinics within its region. As PACS and teleradiology sites become operational, the DoD is developing a better understanding of the capabilities as well as the limitations and economic constraints of technology and communications. All MDIS PACS sites are also capable of functioning as teleradiology hubs. Presently, Madigan Army Medical Center (MAMC) at Fort Lewis in Washington, Brooke Army Medical Center (BAMC) at Fort Sam Houston in Texas, Wright-Patterson Air Force Medical Center (WPMC) in Ohio, and David Grant Air Force Medical Center (DGMC) in California, are undergoing phased implementation of this system. Operational teleradiology installations began in Korea in the Summer of 1993 and in the United States in the Summer of 1994. A "Hub" and four "Spokes" are currently operational in Korea.

In addition to the four PACS sites, spokes at Ft Detrick in Maryland and Holloman AFB in New Mexico, are operational in the United States. Teleradiology sites in progress include: Vance AFB in Oklahoma, Cannon Air Force Base in New Mexico, Wilford Hall Medical Center (WHMC) Lackland AFB and Dyess Air Force Base in Texas, Fairchild AFB in Washington, Mountain Home Air Force Base in Idaho, Fort McPherson and Eisenhower Army Medical Center (EAMC) Fort Gordon in Georgia.
2. System Objectives

The ultimate success of PACS and teleradiology depends on acceptance by the end users, the physicians, and the end product, quality patient care. A viable digital imaging system needs high image quality, a user-friendly interface, qualified radiologists interpreting images, close communications between the clinician, radiology technologist and radiologist, and images which are rapidly accessible to the clinician with a dictated report tied to the image. Medical Treatment Facilities (MTFs) require a highly reliable system with the latitude to shift workloads as necessary both intra-facility and inter-facility coupled with a large database of images for education and research purposes. Included in the formula for success is the minimization of facility modifications and installation expenses; otherwise costs will be prohibitive and an economic pay-back will become impossible.

2.1. PACS Objectives

Physicians are relying more and more on diagnostic imaging for clinical practice which results in an increased volume and demand for these images. Management of this information using a traditional film-based system has become a significant cost driver in both image acquisition and in image storage space. The recent budget cut-backs in military funding have resulted in an immediate need to find new ways to accomplish cost savings in order to reduce medical expenses. The target areas for cost savings can be grouped into two general categories: direct cost savings related to a dysfunctional film-based management system and indirect cost savings related to quality of care provided. Direct costs include such things as film, chemicals, space, personnel, overhead, disposal of processor waste, and lost films which necessitate repeat examinations. Indirect costs are related to system inefficiencies such as misfiled old exams, films kept by physicians for reference and training, and unavailable exams taken at other MTFs; all of which lead to delays in diagnosis, prolongation of hospital stay, and inefficient use of physician time.

A PACS/Hub solution must address these issues in a timely and cost effective manner. It must provide rapid access to diagnostic quality images to both radiologists and clinicians. Finally, it must provide a reliable RIS and a robust image management and archive for long term access to patient exams.

2.2. Teleradiology Objectives

In many rural areas in the continental United States and in remote areas of the world such as Korea, American military clinicians had no practical way to have images reviewed by a radiologist in a timely manner. Clinicians are forced to make treatment plan decisions based on their own interpretation of a radiographic finding. It is not uncommon for a routine radiographic interpretation, with a completed report, to take as long as two weeks to be returned. This inefficient practice sometimes results in patients being flown, via expensive military air evacuation, to distant medical centers because of radiographic findings that are actually only variants of normal. Assignment of a radiologist to these remote locations usually results in an under-utilization of manpower and job dissatisfaction due to the fact that a radiologist assigned to any of these remote areas has very limited access to current clinical cases to stay abreast of new developments in any of the specialized fields as well as no immediate access to consultative assistance.

Any teleradiology solution must also address these issues in a timely and cost effective manner. It must provide rapid access of diagnostic quality images to radiologists and clinicians at both the hub and spoke sites. It must also provide an integrated RIS functionality and image management between the hub and spoke sites. Teleradiology
includes the added cost burden of communications charges. Cost effective communications must be acquired for any successful teleradiology implementation.

3. System Configuration

The MDIS PACS and teleradiology configurations provide a successful implementation to meet the system objectives.\[3,4\] Full image data sets are acquired at both PACS and teleradiology sites with computed radiography (CR) images, digitized film, magnetic resonance (MRI) and computed tomography (CT) images. In the case of teleradiology the exams are transmitted from the spoke, archived on an Optical Disk Jukebox, and then viewed on high resolution (2k) monitors at the PACS/hub site. A radiology information system (RIS) is integrated into the process so that every image is tied to the patient's demographic information, clinical history, and radiological report. The implementation of two-way teleradiology between sites enables workload sharing, peer review, research, and education.

3.1. Image Acquisition

Plain radiography images (chest, bone, abdominal series) can be acquired electronically either by laser digitization of radiographic film (2k resolution, 10 bit gray scale) or by use of CR (2k resolution, 10 bit gray scale contrast). The CR system acquires digital x-ray images directly without film by utilizing reusable photo-stimulable phosphor plate technology. Exposed plates are scanned electro-optically to extract images in digital format. The network can also support the transfer of images directly from existing digital imaging modalities such as CT, magnetic resonance imaging (MRI), and ultrasound (US).

3.2. Display Workstations

The display stations utilized by the MDIS system come in two general categories: standardized and optimized. The soft-copy image displays (SCID) with a suffix indicates the type of workstation utilized. A SCID-S is the standardized radiologist workstation with an "A" class monitor with a 2048 x 1536 pixel matrix. A SCID-O is the clinicians optimized workstation with a "C" class monitor with a 1152 x 882 pixel matrix. Workstations generally have two or four displays. Regardless of the workstation selected, the full image data set is available. The main difference between the two is the through-put time. The SCID-O workstations require use of electronic magnification tools in order to access the full image data set whereas the SCID-S workstations are capable of displaying the full data set of most images upon initial presentation.

3.3. RIS-HIS Interface and Database Management

The Composite Health Care System (CHCS) is a Hospital Information System (HIS) which has been chosen for dissemination throughout the military. The MDIS system has an independent Radiology Information System (RIS) for order entry, dictation, approval and display of reports. This RIS still exists, but a one-way interface from CHCS has been developed where examination orders and transcribed reports are entered into CHCS and electronically shipped to the MDIS RIS. This allows the MTF to utilize a single HIS for all areas of the hospital. The MDIS RIS will become a back-up system, with all information being exchanged through a two-way interface with the CHCS HIS, by the end of 1995.
3.4. Image Engine

The image engine of the MDIS PACS system is the Working Storage Unit (WSU). The WSU functions as the local and short-term storage for images. Loral developed the WSU as a redundant array of inexpensive disks (RAID) device with 40 disks (magnetic media) operating in parallel; 32 disks for a 32 bit word, 7 disks for error correction, and one disk acting as a "hot spare" (single disk failure detected and corrected without loss of operation). The WSU is designed to hold inpatients examinations for the average length of a hospital stay, all outpatients examinations for 48 hours, all exams not yet interpreted, and pertinent historical images.

3.5. Exam Archival

Optical Disk Jukebox: Each Kodak ODJ holds either 50 or 100 (10 GigaByte) WORM 14" optical disks, depending on the workload requirement for the central archive. Computed radiography images are stored with 10:1 lossy compression (modified JPEG format). At 10:1 compression, the 100 platter ODJ can store about one million CR images (the original interpretation of an image by the radiologist is always made on the original data from the WSU before compression is applied).

3.6. Teleradiology Communications

Teleradiology communication requirements for small and large spokes typically require that between approximately 800MB/day and 2400MB/day of image data be transmitted from the spoke to the Hub. The current commercial charges for inter-state high bandwidth communications, with Government and high volume discounts, are about 12 cents/min for each 64kbit/sec channel for daytime usage and 6 cents/min for each 64kbit/sec channel at the night-time rates. The effective bandwidth on each channel is about 56kbit/sec. Without data compression, this equates to a charge of between $114/day and $342/day at the night-time rates. For a 240 day work year this yields between $27,360 and $82,080 per year.

The MDIS contract currently requires that any compression used be bit preserving. The best that a lossless compression algorithm can accomplish on a typical radiographic image is about a 2:1 ratio. Using a data compression rate of 2:1, the communications cost for a small spoke are reduced to an annual charge of between $13,680 and $41,040 respectively. In order to reduce communication costs significantly, the main issue that needs to be resolved is the clinical significance of using non-bit preserving data compression algorithms. Significant improvements in the data compression level used will help to defray communication costs and improve the cost/benefit ratio's for all future teleradiology.

4. System Architecture

4.1. PACS/Hub Architecture

The hub shown in figure 1 is a "pure" hub and does not contain any image acquisition devices; it is used for reads and archiving for remote teleradiology sites only. However, with the addition of the desired image acquisition components as shown in figure 2, it may be built up and utilized as a full PACS site.

The PACS provides the permanent legal record archive of all images sent to it from the spokes. A radiologist at a spoke will "call-in" to the hub to retrieve old exams for comparison with current exams. The exams will be retrieved from the hub's ODJ and sent out via the 1.54 Mbit/sec T-1 line. The hub and spoke can also connect to each other via VAX modems for remote access for software upgrades and database maintenance.
4.2. Teleradiology Architecture

The MDIS teleradiology sites are currently available as either small or large. The small spoke is designed to support a medical clinic with an image load of up to 100 images per day. The small spoke is structured for a clinic which has no radiologist assigned and clinicians rely on their own "wet" read followed by a radiologist's interpretation at a later time. This radiology interpretation is typically done by a contract radiologist who comes in once or twice a week for plain film interpretation and special procedures such as fluoroscopy, ultrasound, and mammography studies. The small spoke architecture is limited to a single SCID-O which is multi-tasked and conducts its support activities serially; each service must complete before the next support activity can start. The large spoke is designed for a medical facility with an image load of up to 350 images per day. The large spoke architecture is structured for a medical facility which may or may not have a full time radiologist assigned. The architecture supports "filmless" operation at the site with both radiology soft-copy interpretation workstations and clinician workstations. Figure 3 shows the basic architecture of a large spoke. It is configured with two workstations, a SCID-S which serves as the radiologists workstation and a SCID-O workstation which is multi-purposed serving as the TRS and the Quality Control (QC) station. The RIS has been incorporated for parallel radiology reception/administration activities and exam acquisition.

4. Operational Flow

The flow of a radiology exam at the small and large spokes follows:
- Patient enters radiology reception. Local Database Query: Is Patient Known?
  - Yes: Order Scheduled / Patient "Arrived",
  - No: Patient entered, demographic data entered, order scheduled
- Local Database is Updated with Patient Information, Exam is Scheduled/Ordered
  Upon Arrival, Bar code is printed or Acquisition Worklist Updated
- Exam Initiated
- Verify Patient Data and Exam Priority (STAT, Wet, Routine)
- Read CR Plate
- Image Stored to local disk
- Conduct QC
- Image, Patient, and Exam data transmitted to designated reading location, via the TRS, in either Automatic Batch mode or STAT mode or Manual push to location
- Exams pushed from spoke stored on and read from local disk at Hub
- Report transcribed to database and available for view via query from spoke
- Automatic Transmission of Report back to spoke

Figure 2. PACS/Hub

5. Lessons Learned

5.1. Training

An interesting lesson learned during MDIS PACS and teleradiology implementation is one of training. Although the MDIS workstations are user friendly, software upgrades which have more functionality, but increased complexity also require additional training. If the end users do not feel completely comfortable with the acquisition modalities and workstation features, they will be misused and under-utilized. Teleradiology site personnel experience extreme anxiety when training is deficient since they have to rely on "remote" support for radiological support. Unfortunately, training for physicians is often difficult to schedule and complete. Video tele-conferencing and scheduled weekly training sessions are a few solutions to get all users trained and comfortable.

5.2. Image Quality

Bringing a new technology into a MTF will always be a challenge. Quality control, training, comprehensive product reliability testing, good communications between design engineers and end users, and digital integration of different modalities are all critical issues. Switching a MTF over to a filmless digital environment requires comprehensive methods
for quality control. With quality control, every link in the imaging chain must be analyzed. The image acquisition devices must be checked daily for calibration. The workstation monitors must be checked on at least a monthly basis for brightness, variation across a screen, contrast resolution, and the level of noise. The database integrity must be monitored daily to ensure that all exams are available and accessible. The users must be queried on a regular basis to ensure that necessary changes and system upgrades are planned and implemented.

Several areas of the MTF can readily operate in the filmless mode. However, significant changes must be made for "all" sections of an MTF to become filmless. Teleradiology sites are especially susceptible to quality control problems. The spoke architecture is composed of "one each" workstation and modality which makes comparison testing impossible. They typically do not have all required test equipment, limited spares, and a limited number of fully trained personnel on site. Improved logistics support and training are needed to improve filmless operation for the teleradiology sites.

The general practitioners and clinicians tend to truly appreciate the access to radiological exams in a timely and efficient manner. Most of them claim to save up to an hour per day of time because they are no longer waiting for films to be found or waiting in line for films to be fetched from a file room. The quality of softcopy imagery acquired on CR modalities has been proven adequate and is no longer a clinical diagnostic issue; however, radiologists believe that PACS is useful, but workload is not reduced and softcopy throughput is not yet up to the speed of reading pre-hung films. Significant workstation speed-up improvements have been requested and are due in the Sep 1995 timeframe. These improvements include things such as intelligent pre-fetching of historical exams, default display protocols, faster workstation hardware, and a restructuring of the database software.
5.3. Communications

When teleradiology is the sole mode to support imaging for a medical treatment facility, the reliability of the system is critical in that it directly affects patient care. If the communications link goes down, the system must be able to still function; storing images and then sending them later when the communications are restored. This need developed into the requirement for all MDIS sites to have removable media, in our case the magneto-optic drives. If communications are out for an extended period of time, local softcopy archive is now possible. If necessary, the M.O. disks can be mailed to the hub at a later date for permanent archival onto the ODJ.

To ensure the viability of teleradiology, clinically acceptable variable data compression rates for teleradiology or alternative lower cost communication links must be developed in order to reduce annual communication charges. Multiple communication links and redundant archives must be considered to prevent accidental loss of irreplaceable patient exams.

5.4. Two-Way Teleradiology

Shared contractor/Government maintenance programs need to be developed to maintain the up-time of equipment in remote areas. Comprehensive operator procedures and manuals must be developed, documented, and maintained for proper operation and maintenance of the technologies employed at both PACS and teleradiology sites. To operate in a remote filmless environment, fail-safe procedures and back-up systems must be considered and planned for every step of the way. Concepts and operational procedures must be refined for workload sharing between sites, radiological consultations, and educational programs. Cost/benefit analysis must be done carefully to ensure that economic payback is feasible and achievable.

6. Summary

PACS combined with teleradiology provides immediate qualified radiology support both in house and to remote sites that would normally wait days for diagnostic interpretations of their images. The support of clinical consultations allows the "experts" to be shared by all. Employing the MDIS PACS, an integrated RIS, and two-way transmission of images for teleradiology, a virtual radiology department has been developed that is truly time and distant independent. Given that improvements are possible in the areas of quality control, training, and data compression, PACS and teleradiology can be both operationally and economically viable.

References: