Experience with Wide-Area Network Nuclear Medicine PACS

Paul E. Christian, Donald A. Baune and Frederick L. Datz

University of Utah Health Sciences Center, Salt Lake City, Utah

This article reviews our experience with designing, implementing and operating a nuclear medicine picture archiving and communications system (PACS). PACS hardware, software and changes in the professional tasks for both technologists and physicians are presented. Educational and research benefits are also discussed.

Key Words: wide-area networks; computer network design; picture archiving communications systems

J Nucl Med Technol 1996; 24:329-335

Viewing nuclear medicine studies on the imaging computer monitor has become a necessity for many nuclear medicine practitioners. The commercial availability of SPECT imaging in the early 1980s created the availability of computers with significantly increased computing power. Modern scintillation cameras have the computer integrated directly into the camera's imaging system. Therefore, it is no longer possible to acquire nondigitized images. The emergence of computer-generated images has also resulted in improved resolution and quality of display screens. The ability to control display brightness, contrast, background subtraction and a variety of color tables has made digital viewing desirable over conventional film. Overexposed or underexposed films requiring repeat imaging of the patient or rephotographing are eliminated. Digital viewing also enables physicians to view studies cinematically and to process regions of interest, curves, etc. These advantages of digital viewing made us want to establish a picture archiving and communications system (PACS) for routine use in our department. In this article, we discuss design considerations, construction and 3 yr of experience using a wide-area network (WAN) PACS and teleradiology system that links three hospitals.

PACS AND NETWORK DESIGN

Two primary characteristics were established for our PACS: (a) the system needed to provide improved access to nuclear medicine images from any hospital or imaging device and (b) the system must provide geographic freedom for physicians and technologists. The key components of PACS are: network from camera computers, an image management computer (and database of files), image storage devices and image display stations (*1,2*). We intended that our system would not only contain these required components but would utilize these devices and data management over a WAN.

Criteria were developed to describe the desired features we wanted have in the PACS network (Table 1). The initial phase of the system had to be inexpensive, costing less than $70,000. It needed to have a reasonable file transfer time and be able to handle large image databases and large image files. The system had to be user-friendly and provide geographic freedom for technologists and physicians to view and process images from any workstation on the network. Also, the system needed to be reliable, with redundant options for image viewing. The system needed low maintenance and have the capability of remote system administration from the primary site. Our PACS had to provide software for digital viewing of any study from any of the three institutions with on-line or near-line permanent image storage.

The system was planned and implemented after the steps listed in Table 2 to cautiously approach this new development and ensure its success. Feasibility was determined by testing the utility of the open-systems environment between general Unix (Sun Microsystems, Mountain View, CA) computer systems and Unix-based commercial nuclear medicine software and determining their compatibility when networked. We needed to test network file system (NFS) mounting of disks from remote computers and the redirection of applications software from a commercial nuclear medicine computer onto another workstation. These capabilities and any limitations were used to set the system design.

We determined that the optimal functionality of our PACS necessitated a pair of workstation computers in each physician work area (Fig. 1). This arrangement would allow display of many images of a particular study or side-by-side comparison of old and new studies, or the display of a nuclear medicine study on one screen and the display of a radiograph, CT or other digitized image on the other system monitor.

For correspondence or reprints contact: Paul E. Christian, CNMT, FSNMTS, Nuclear Medicine, University of Utah Health Sciences Center, 50 N. Medical Dr., Salt Lake City, UT 84132.

TABLE 1
Desired Features Considered in Designing PACS

- Inexpensive
- Reliable
- Use industry standard systems and devices
- Low maintenance
- Simple
- Remote system administration
- Reasonable file transfer time
- User-friendly
- Geographic freedom for users
- Flexible image processing
- Large patient database

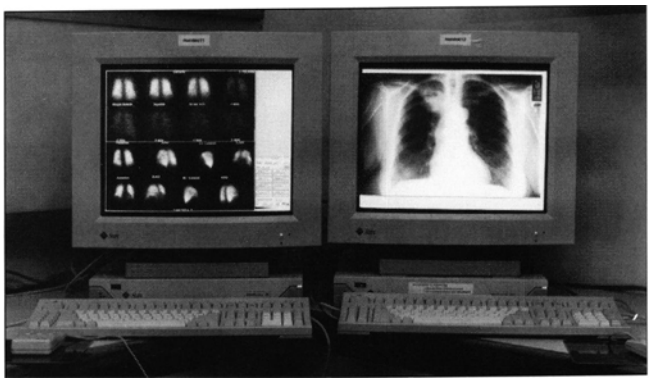

FIGURE 1. Pairs of Unix workstations at each physician work area in the reading room provide adequate display systems for image review and correlation.

PACS HARDWARE

Unix workstations were selected for use for our PACS because of the client/server relationship and open-systems environment. Unix workstations have an easy-to-use graphical user interface (GUI), which is also in a multitasking and multi-user environment. The screen resolution is 1024 × 1280 pixels on 19- or 20-inch color monitors. The generic Unix workstations provided a general viewing system that could also be used for general office applications in addition to research in image processing and SPECT.

Based on our design criteria and budget, we determined that we could begin our system by purchasing a file server, four new workstations and use existing diskless workstations. Also, we purchased 11 gigabytes of on-line disk storage, a tape backup system, a 10baseT hub and cable. A color printer was also purchased for use as a marketing tool to send selected images to referring physicians. Physician work areas in the reading room of each institution are equipped with a pair of workstations. Additional systems were soon purchased to provide viewing stations in faculty offices and their home offices for viewing after-hours emergency studies. Two of the hospitals required a computer (Numa, Worcester, MA) that could convert files on diskette from one manufacturer's format into Interfile format and transfer the data to the PACS at the university.

Upon delivery of all the equipment, it took 3 wk to install system software on each computer and prepare user accounts and script software for automated starting of redirected windows and other viewing programs. Testing of both hardware and software took about 1.5 wk. To reduce expenses, we installed the 10baseT cabling throughout the department ourselves. Thorough testing of all lines was performed to ensure that each system would function properly as soon as it was installed to allow prompt clinical use.

Our initial PACS immediately expanded under a separate cost center to a WAN to include the VA Medical Center and a community hospital (Fig. 2). An ethernet speed (10 Mbps) microwave connection existed between the ethernet backbone of the University Medical Center and an ethernet network at the VA hospital. Therefore, nuclear medicine networks at the two hospitals could be connected as though they were one. Access to a community hospital was established by leasing a T1 line from the telephone company, which gave us our own dedicated line with a speed of 1.54 Mbps. A router and CSU/DSU were placed on the T1 line at the community hospital to provide an ethernet network to the image translation and Sun computers. The addition of two hospitals also created the need to perform telenuclear medicine as well as teleradiology and telemedicine.

TABLE 2
Primary steps for PACS implementation

- Feasibility
- Design
- Equipment specification
- Equipment selection
- Equipment purchase
- Pre-installation testing
- Installation
- Final testing
- Clinical use

HARDWARE ENHANCEMENTS SINCE INSTALLATION

Our fileserver was initially established with 11 gigabytes of external disk storage. Since installation, the server has been upgraded to a Sun Ultra SPARC 170 with 38 gigabytes of disk space. Also, near-line storage for studies older than 4 mo can now be held on a high-speed tape jukebox with a total storage capacity of one terabyte and a file retrieval time of about 2.5 min. The permanent index of all patient studies is held on disk along with the name of the image file directory to be recalled from tape.

Our initial network at the university was part of the network of the imaging research laboratory which included CT and MRI. Traffic on this network would occasionally be very heavy, particularly in the afternoon. A dedicated nuclear medicine subnet was created using a LANNET hub (LANNET, Inc., Irvine, CA) to restrict only traffic local between nuclear medicine systems. This reduced traffic significantly. There also was a tremendous reduction in error and collision packets during peak use.

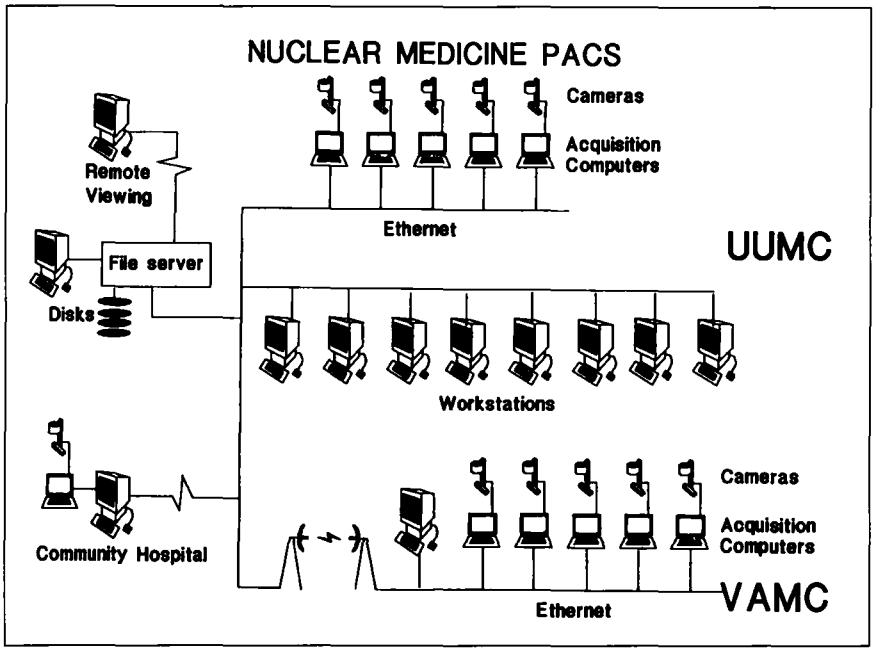

FIGURE 2. WAN diagram of the three hospitals connected by microwave or T1 lines link the ethernet networks in nuclear medicine at each hospital.

TELERADIOLOGY HARDWARE

In addition to nuclear medicine images, other information is required for interpretation of patient studies. Physicians need to review the requisition and chart, talk with the technologist and patient and see old studies and images from other modalities. Hardware for telemedicine was needed at all sites to allow non-nuclear medicine information to be communicated to other sites. This additional hardware included a fax machine to allow communication of patient requisitions and other necessary documents. Telephones in the patient areas allow the physicians to directly communicate with patients about their studies and direct the technologist in obtaining additional views, image processing, etc. Medical images that were on film, such as radiographs, CT or old nuclear medicine studies could be digitized using a flat-bed scanner (Sharp, Mahwah, NJ) attached to a Sun computer. This computer also controlled a videocamera that could be used to capture a static picture of a portion of the patient's body that might provide additional visual data to the physician interpreting the nuclear medicine study. Digitized films or video files are sent to the university using file transfer protocol (ftp). Films were usually digitized using 75 lines per inch resolution and can be transferred in about 39 sec. This resolution is adequate for use as complimentary medical information but is slightly less than what would be optimal for primary interpretation of radiograph films.

The hardware and software we developed for this WAN PACS have provided the infrastructure necessary to handle PACS at our own hospital. With this infrastructure, we have developed a mechanism whereby it is easy to add outside hospitals to the system, thereby allowing us to provide effective professional image interpretation services.

SOFTWARE

Our PACS relies heavily on the client/server relationship of Unix systems to allow applications software to be displayed on another workstation. Shell script programs were written and placed in the ".login" file so that the script is executed automatically when user logs in. A shell script was also written on the commercial nuclear medicine computers to start display and processing applications programs back onto the remote system (*3*). Therefore, when the physicians boot up the Sun computers in the reading room, the display windows from the commercial nuclear medicine computer automatically appear. Redundancy of the display software is provided from accounts and viewing script software from any of five nuclear medicine imaging computers at the university and two at the VA Medical Center. Although the user's login assigns the display software to come from a particular nuclear medicine computer, viewing software from another dedicated nuclear medicine computer may be accessed to provide a backup alternative software source when a system might be down. This redundancy has given us remarkable uptime. We have had less than 2 hr of total downtime in 3 yr, most of which is less than the 5 min it takes to reboot the fileserver for the user accounts.

The use of a NFS, which is available on each of our computers, allows cross-mounting of disk file systems from other systems on our WAN. NFS provides file portability, thereby making remote disk files accessible as though the disk with files is on the local computer. Therefore, physicians can view studies from the camera-computers without leaving the reading room. Likewise, technologists can work from any system in the department to process studies from computers anywhere in the department or even from another hospital.

Software tests included simultaneous display of a particular file on several different systems and performing network and server load testing. Our system allows viewing of an image file simultaneously by several users. Network and server load tests were performed to ensure that systems did not crash during peak use periods. Load tests were performed by creating multiple complex tasks, such as remote display of several cinematic displays at one time along with computationally demanding

functions (SPECT reconstruction), all performed simultaneously at many workstations from only one nuclear medicine computer (Odyssey, Picker Intl., Inc., Bedford Heights, OH). Although some network and system slowdown occurred, the system did not crash.

We determined that it would be most efficient to convert all nuclear medicine images into one file format that could be displayed on the majority of nuclear medicine computers and by all viewing workstation computers. Several different manufacturers cameras were in use throughout the three hospitals. Two hospitals required installation of an image translation computer to read a variety of disk sizes and image file formats. This system (NUMA, Worcester, MA) reads image files from disk, converts the files into Interfile format and then delivers the converted file to another computer. Our destination computer at the university automatically checks for newly arrived Interfile datasets every 2 min and converts them into the final file format.

Although file migration could be performed by an automated or manual system, we elected to use manual file migration on our PACS. When the technologist has obtained all images of the patient, the patient study directory is transferred to the file server using a script program that we wrote. When a file is transferred from the imaging computers to a PACS disk file, permissions are automatically changed to protect the data. In our system, users can view and manipulate images, but only the system administrator owner of the file can delete image data. These ownership properties ensure the availability and security of patient image files. Only system administrators have root access to maintain file status as needed.

Initially, our physicians tried viewing raw images. However, they found that it was too time-consuming to retrieve various image files and preferred that the technologists prepare saved screen files for interpretation. The saved screens allow mixed images to be viewed with appropriate patient demographics, text and other labels on the images. Physicians can select saved screen files and rapidly review a series of patient studies without expending even a few extra seconds to search for each patient study in the database.

The file format of video and digitized images is not supported by our nuclear medicine viewing software. The file formats of these images were most commonly PBM, raster and TIFF. We use a generic X-Windows display software package that allows a variety of image formats to be displayed as well as operator control of the gray scale, brightness, enhancement, etc. The multitasking capability of our computers allows display of the nuclear medicine study on the same screen as these other images, if desired.

Given the number of viewing computers on this WAN, we were concerned about quality control of image display. We control the resolution, brightness and contrast of different computer monitors by using one standard gray-scale pattern that can be viewed on each system. Once the viewing station has been checked with the quality-control display pattern, the brightness and contrast settings are locked so that only the system administrator can readjust the monitors. Monitors are periodically checked with this pattern since settings will change as the monitor ages, or until it must be replaced. This gray-scale pattern has also been transferred to films that are scanned on the film digitizer for quality control.

Before the PACS was fully implemented, physicians and technologists were given an overview on all aspects of using the system through a 15-min video presentation. The video introduces booting systems, using accounts and passwords, how to view images with different pieces of software and how to shut down the system. All personnel were given formal training sessions after the video presentation. The tape could then be used as a reference tool, which significantly reduced the number of questions from users. New users of the system watch the videotape and practice on the system before formal training.

Within a few months, we plan to have a radiology PACS available at the university hospital. We plan to have automated conversion software send saved screen files to the radiology PACS in DICOM format. This will provide nuclear medicine studies throughout the radiology department, wards, clinics, etc., without having to extend our nuclear medicine mini-PACS throughout the institution. Since DICOM image format cannot be used by nuclear medicine computers for reprocessing data, we will retain the nuclear medicine PACS for interdepartmental use. The radiology PACS, however, will allow that department to be completely filmless.

EFFECT ON WORK HABITS

Technologists

With modern scintillation camera systems having computers integrated into the system, the technologist spends some time after image acquisition preparing the study for filming. The images are formatted into a logical presentation and the patient name, medical record number, date, etc. are added to the display for documentation. Instead of capturing data on film, our technologists now simply save the screen to disk, thereby providing an electronic archive of the study. This process represents time savings for the technologist and patient. Since no time is required to develop film, physicians may check the study before the patient leaves the department.

The technologist, by intercom, may alert the resident in the reading room that the study is ready for review on the viewing station before the patient leaves the imaging room, or the technologist may go to the reading room and retreive the digital study on the computer monitor for the resident's review. Once all images have been obtained, the technologist will type a command on the computer to transfer the study to the PACS' archive disk, where the study is protected from possible deletion. The technologist can make a film copy for the radiology film jacket at a later, more convenient time.

Nuclear Medicine Physicians

Nuclear medicine physicians and radiology residents have had to change their work habits somewhat in using a PACS instead of routine film viewing. Saved screens with multiple images, patient demographics, etc. have been a significant enhancement in reducing image retrieval time and provide more convenient viewing as opposed to viewing individual raw

image files. The saved screens provide the additional patient data that a physician may have with filmed images. With our software, the physician can retrieve several saved screens relevant to one or several patient studies and view these screens rapidly for study interpretation or review with the referring physician. In the worse case scenario, patient file availability and display takes approximately 17 sec.

Physicians also save time using PACS. Effective use of the optional software searches by date and file type, such as saved screen files, can reduce the time a physician spends looking through several large files for a specific patient or group of patients. Although image files once selected appear on the screen in only a few seconds, most of our physicians believe that they could read film studies faster when they are reading alone. In a teaching institution such as ours, reading sessions with residents do take time, but we believe that there is little difference in total readout time between film and digital viewing.

Digital viewing is particularly advantageous when interpreting SPECT or gated images. Viewing stations in the reading room provide quick access to evaluating motion or attenuation on SPECT studies through cinematic display. LVEF can be quickly calculated and correlated with wall motion and are not delayed by the need to go to the imaging or computer room. Our WAN PACS have provided geographic freedom for our physicians by making images from the other institutions directly available to any terminal in the department, reading room or faculty offices. Patient care is definitely improved by the immediate availability of physicians to direct patient procedures and view images before the patient leaves the department, even at another hospital. With film viewing, however, it may be many hours before a faculty physician can read the study. Interestingly, WAN PACS makes it possible to quickly obtain a second opinion on a case by a faculty physician at one of the hospitals.

Home viewing of image files by faculty nuclear medicine physicians has been performed on Sun computers in their residence using a point-to-point protocol (PPP) via standard telephone lines. Image files had to be FTPd to the local disk, after which generic X-windows viewing software is used for image display. A 1-megabyte saved screen file takes approximately 5–10 min to transfer if the file is compressed. The Sun workstations allow for unattended transfer, so the physician could be notified after the files have been transferred. We have improved home viewing capabilities significantly with ISDN high-speed data phone lines, which provide sufficient speed to run viewing applications software redirected to home computers in the same way that we redirect viewing applications software to the reading room viewing stations. With ISND, it now takes less than 2 min to transfer a 1-megabyte file.

Referring Physicians

Referring physicians appreciate PACS because they know that the images are digitally available on our systems. Our films are stored in the radiology film jacket, which may be checked out, lost or misplaced. There have been no complaints about our decision to provide only one or two films of the study in the film jacket. Referring physicians are confident that the patient's status has been documented by the selected films in the folder.

The PACS has been a good public relations/marketing tool with referring physicians. Physicians see our nuclear medicine department as state-of-the-art with immediate availability of patient studies, which translates into an emphasis on quality patient care. We have seen no significant effect on the volume of nuclear medicine procedures with PACS. We have not identified any additional service, nor have physicians shied away from nuclear medicine due to limited number of films available in the film jacket. Digital viewing of studies in the department has enhanced the communication between the nuclear medicine physician and the referring physicians.

NETWORK AND PACS EDUCATIONAL USES

Our network has provided a wide variety of benefits that relate to education and research. Of primary assistance to the departments has been the addition of teleconferencing software (ShowMe™, Sun Microsystems, Mountain View, CA) (Fig. 3). This software allows conferencing from any site on the Internet with compatible software (*4,5*). Within our WAN, the microwave link to the VA provides effective high-speed communication for teleconferencing. The software allows several users to log into the conference and view the same image in the conferencing window. The teaching cases used with this software are digital images from teaching archives stored on disk and are displayed by the lecturer by dragging and dropping the file into the conference image window, which can be viewed by on all logged-in terminals. Each user logged into the conference has their own colored cursor to point to an area of the image displayed by the conference host. Arrows, lines and text can be added and erased by each person independently. Because of teleconferencing, travel time to attend conferences at other institutions has been eliminated. In addition, teleconferencing ensures physician availability at her institution in the event of an emergency. Teleconferencing also provides residents, fellows and, occasionally, technologist students with hands-on experience with state-of-the-art resources.

The PACS significantly increases the number of interesting cases that may be added to digital teaching file directories. Teaching files may also be put on optical disks or photo-CDs. Faculty physicians can capture digital cases from the PACS easily and may also save them in an appropriate file format for use with photo-CD, which can then be viewed on the institution's computer system or at home on a portable photo player that plugs into a television.

The PACS also contains a large number of patient studies that can be accessed for research projects. In addition, research images can be copied to a specific disk during work on a project. The WAN makes it possible for researchers to obtain access to their files from any hospital, office or home system, thereby improving productivity.

OBSERVATIONS ABOUT USING PACS

During the 3 yr that we have used the PACS, we have found it to be a good marketing tool for referring physicians. The

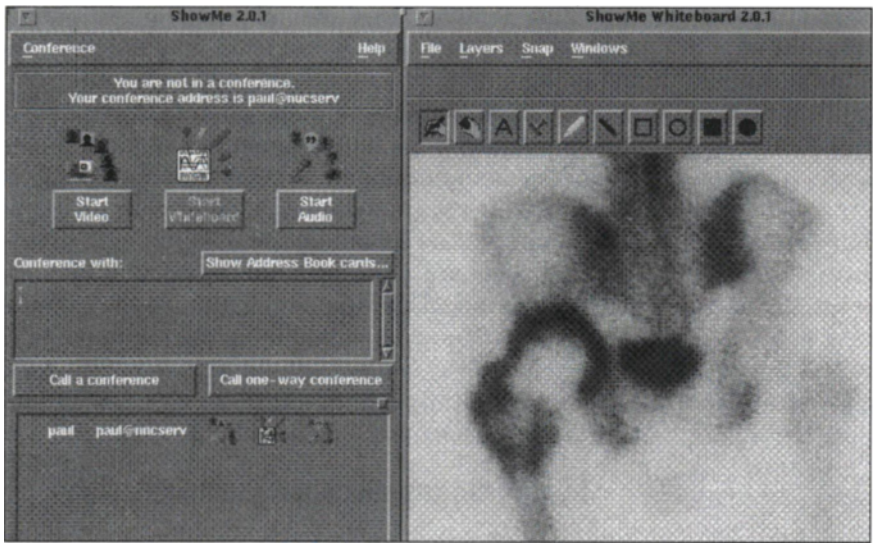

FIGURE 3. ShowMe™ teleconferencing software used for interactive teaching.

system allows us to more quickly locate images for review with referring physicians. Image retrieval time is, at most, about 17 sec for our system, which includes: time to search by either patient name, date or medical record number; retrieve the image; and display the image on the screen.

System uptime has been excellent, with less than 2 hr of downtime in 3 yr. Most of the downtime has been a few minutes while rebooting the file server. Redundancy of our viewing systems ensures that we are never completely down for image viewing, except for a short power outage. We now have uninterruptable power supplies on the hub and imaging systems, and on one computer in the reading room enable image viewing even during power outages. Our worst system downtime occurred when we lost one of the two CPUs in the server and part, but not all, of the system was down while the bad CPU was removed and the server rebooted. This was a valuable experience in the importance of having redundant systems and software sources.

We have found it necessary to put one or two representative films documenting the extent of disease or normalcy of the study in the radiology jacket for the convenience of the referring physicians. We experimented with putting one or two systems in the radiology department and letting referring physicians and radiologists view from the general radiology reading room. Those systems have been tremendously underutilized and were returned to nuclear medicine.

The system has been easy for new technologists and physicians to learn. As previously stated, staff received an overview of the system through a video presentation, which is a valuable training resource and time saver. Formal training always follows the video presentation to answer specific questions and ensure a level of understanding and confidence for the new users.

Despite these apparent advantages, many nuclear medicine practitioners question the utility of a PACS in several areas. First, is it cheaper than film? We have reduced film costs from expenses before PACS. We are now spending only 35% of our former budget for film and developing. Direct expenses of operating and maintaining a film processor have not been reduced. We should be filmless when the radiology PACS that can store nuclear medicine DICOM images is operational.

Has PACS provided cost savings to our department? Yes, it has relative to the cost of individual storage of patient data instead of film. The break-even time financially for our whole system is 7–8 yr. However, we will be changing the system as it ages. Each component will probably have only a 3–5-yr useful life. Therefore, it is not providing an overall cost savings due to total equipment costs.

Do we have fewer personnel? We did not need to add any personnel. The authors of this article designed, built and maintain the system. Personnel costs have not been reduced, but technologists can now spend more time directly with the patient since there is now no need for them to leave the imaging room to go to the darkroom and develop the film before a physician reviews the study.

Is PACS as fast as film? It is faster than films, especially when the time it takes to locate a film jacket is considered. Also, at our institution, the nuclear medicine image is a subinsert in the radiology jacket. If we did not have the film in our reading room, somebody would have to walk to another wing of the hospital to the file room and retrieve the film.

One clinical advantage of our WAN PACS and teleradiology system has been increased availability of images. Everyone is plagued by the problem of checked-out film folders, lost films and so forth. Our PACS has provided quick availability of all patient studies since the system's installation. We have fewer repeat studies because the image intensity and contrast can be manipulated as the individual physician desires.

CONCLUSION

We have had an extremely positive experience implementing our WAN PACS. It has been much more convenient for both faculty and resident physicians to review cases as they are being performed. Faculty physicians could even be in another hospital staffing assignment and review studies and order additional views or procedures during the patient's stay in the

department. A WAN PACS allows nuclear medicine physicians more geographic freedom in their staffing assignments. Frequently, the faculty physician may be in his office reviewing studies while the resident reviews the study at a different terminal in the reading room. Meanwhile, they can discuss the case over the intercom or telephone. Teleconferencing has been a significant time saver in eliminating travel time to and from another hospital for teaching sessions and keeps physicians in the department should they be needed by the technical staff.

Technologists have found the system convenient to use and no more difficult than preparing images for photographing. They do appreciate the small reduction in time that is saved by not having to develop films immediately for preliminary review by our residents. Most importantly, however, we feel that we have improved patient care through improved technologist and physician access to images.

REFERENCES

1. Cannavo, M. Components of PACS. In: *Understanding PACS: picture archiving and communications systems*. SCAR; 1992.
2. Datz FL, Baune DA, Christian PE. The all-digital nuclear medicine department. In: Freeman LM, ed. *Nuclear medicine annual: 1996*. New York: Raven Press; 1996:259–284.
3. Datz, FL, Baune DA, Christian, PE. Redirection of client/server relationship of X-Window system as a simple, low-cost, departmental picture archiving and communication system solution for nuclear medicine. *J Digit Imaging* 1994;7:107–112.
4. Christian PE, Baune DA, Datz FL. Clinical and educational PACS and teleradiology using UNIX workstations. http://gamma.wustl.edu/conf2_95/christian/PACS.html.
5. Datz, FL, Baune D, Christian PE, Valdivia S. The use of computer conferencing to allow viewbox-style teaching sessions with residents at outlying hospitals. *Acad Radiol* 1996;3:77–79.