Systems for Remote Interpretation of Emergency Studies

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Telenuclear medicine facilitates a timely expert interpretation of emergency nuclear medicine studies. Current, high-speed Internet connection allows nuclear medicine physicians to be on-call from their homes. Software to support telenuclear medicine is becoming more widely available, although the design of some departments makes implementation difficult. Quality control of the remote monitor requires special attention to ensure correct interpretation. Fortunately, monitor quality control can be performed quickly using relatively simple procedures. Thus, expert interpretation of emergency nuclear medicine studies is practical.

TIMELY EXPERT INTERPRETATION of emergency nuclear medicine studies requires an on-call nuclear medicine physician to have rapid access to diagnostic-quality nuclear medicine data and appropriate correlative studies. Fortunately, it is possible to implement high quality telenuclear medicine at a reasonable cost. The Society of Nuclear Medicine has recently published a telenuclear medicine guideline that outlines the capabilities needed for a telenuclear medicine system.[1] Telenuclear medicine was the subject of an April 1998 issue of *Seminars in Nuclear Medicine*.[2]

Telenuclear medicine systems are available from nearly all the nuclear medicine equipment vendors. In addition, a telenuclear medicine system can be constructed from public domain software with a moderate effort. This article will describe some of the important considerations for implementing telenuclear medicine, with a special emphasis on quality control of remote monitors.

COMMUNICATION SPEED

Compared with teleradiology, telenuclear medicine is not demanding in terms of communication speed. Boston's Beth Israel Hospital Division of Nuclear Medicine began using remote modem communication in 1981, with 4,800 bits per second modems that were considered high-speed at the time.[3] Study transmission times for on-call cases were often 5 to 10 minutes, even for small sized studies. Fortunately, current telephone modem speeds (56 kilobits per second) are practical for transmitting most nuclear medicine studies. (See Table 2 in the editorial by Wallis.[4]) However, typical image matrix sizes have also increased over the last 10 to 15 years to take advantage of increases in camera resolution. So, some delay persists in image transmission, and transmission of correlative images can be time-consuming.

The Beth Israel Hospital introduced cable modem communication in 1996.[5] High-speed Internet connection, either over cable or Asymmetric Digital Subscriber Line (ADSL), is now widely available. It makes transmission of nuclear medicine and correlative images fast and efficient. Even if the telenuclear medicine site has a high-speed Internet connection, there is value to independent telephone service. A dial-up Internet connection can provide a backup connection that is acceptable for on-call nuclear medicine.

File transfer times are a function of the connection speed and file size. An example of a large-sized nuclear medicine study is a dynamic gastrointestinal bleeding study (128 x 128 matrix size in 2-byte mode); each frame is 32 kilobytes, and an hour's worth of imaging (at 1 frame per minute) is almost 2 megabytes in size. A 56 kilo**bits** per second modem connection would likely transfer at less than 5 kilo**bytes** per second, and, thus, require over 6 minutes to transfer the examination, assuming no data compression was used. Transfer by a high-speed (ADSL or cable modem) Internet connection would likely be at least 500 to 1,000 kilobits per second, and, thus, be more than 10-fold faster, requiring about half a minute or less to transfer the study.[6]

The use of data compression can further reduce image transmission times. Compression methods can be considered in 2 categories, "lossless" and "lossy." Lossless compression allows the completely accurate reproduction of the original data set at the receiving end, and typically achieves about 3-threefold compression for nuclear medicine data. Examples of lossless compression include the compression algorithms commonly used for personal computer files (eg, zip, gzip, stuffit) and a few specific image compression formats (eg, GIF, PNG). Lossy compression formats allow higher compression of images by trading off image quality for file size. Images compressed by lossy algorithms (eg, JPEG, JPEG2000, Wavelet) are difficult to distinguish from the original at compression levels of 10 to 20-fold.

TELENUCLEAR MEDICINE FUNCTIONS

The capabilities required for a telenuclear medicine system are outlined in a Society of Nuclear Medicine guideline.[1] Basically, the telenuclear medicine system

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should provide the same capabilities that are used for interpretation within the department, including cine and gray-scale adjustment. In addition to display, some processing capabilities may also be required. The display of cardiac images comparable with display within the department may be the most difficult capability to implement.

TELENUCLEAR MEDICINE SYSTEM DESIGN

Telenuclear medicine systems require components at both the hospital (sending) and home (receiving) end. Telenuclear medicine systems can vary regarding where the image files reside, the communication method, and where image-processing functions occur.

Vendor Workstations

The remote workstation can be the same or similar to the workstations used within the main department. Vendor workstations will likely function by sending the complete patient file from the hospital to the remote site, with all subsequent image processing occurring at the remote site. The advantage of using the same or a similar application is that the physician does not need to learn how to operate a new system; he/she has the same commands available in the department and at the telenuclear medicine site. The disadvantage of this design is that it may be relatively expensive, and some systems do not offer a remote option.

Remote Communications

The remote workstation can be connected to the department through disk sharing, allowing the image files to be stored at the hospital but accessed from home as if it were another "local" drive. If disk sharing is used within the department for connecting systems, then the remote workstation can be made to mimic the operation of the systems in the department. Some of the protocols that allow disk sharing are Network File System on Unix, Server Message Block on Windows, and AppleShare on Macintosh systems.

The X window protocol is an image display protocol used on Unix workstations that allows for flexibility in the location of the display. When used for telenuclear medicine, this protocol allows both the files and all image processing functions to reside at the hospital end. Only the screen display is shifted to the home computer, giving the remote workstation the same appearance as the department system. For nuclear medicine systems that use X window displays, the telenuclear medicine site only requires a personal computer with software designed to emulate an X window display.[7] Similar functionality can also be obtained in the Macintosh and Windows environments using commercial products such as Timbuktu (Netopia, Inc., Emeryville, CA).

Although disk sharing and the X window protocol have worked well in some environments, modern network communications tend to discourage these methods of connecting remote systems. Hospital firewalls tend to block all but a limited set of "safe" protocols. In addition, methods that shift only the display to the home location tend to require very fast connections because each screen modification must be retransmitted to the remote viewing station. This process tends to slow down gray-scale adjustment and may limit cine capability.

Other methods that can be used for file transmission include File Transfer Protocol (FTP) and Digital Imaging and Communication in Medicine (DICOM). FTP is a general-purpose method for shipping files on the Internet, and programs for receiving and sending files by this method are freely available for a wide variety of computer systems. DICOM is widely used within radiology but is just now starting to be used in nuclear medicine. DICOM sending and receiving programs are more likely to be found in commercial systems, although a few free or low cost products are available. As discussed in more detail later, the World Wide Web provides yet another method for image transmission.

World Wide Web

The World Wide Web protocol is the most widely used Internet communication standard. It uses Hypertext Transfer Protocol (http) or https for secure transfers. Many telenuclear medicine systems now use the web for communications. The system in the department is set up as a web server. The telenuclear medicine system is a web client. It can then access the data directly or it can use a web browser to assist with the server communication, with subsequent display by one of the methods listed later.

There are 3 ways that a web browser can be used to access and display image data. (See Fig 1, p.169 in Wallis and Parker.[8]) First, the image data can be viewed directly in the browser. However, browsers do not intrinsically provide image manipulation capabilities needed for interpretation. The web access to the nuclear medicine system at the Beth Israel Deaconess Medical Center allows the user to select a display window. To adjust the display intensity, the user changes the window, and the server retransmits the image with this new window setting. Although this capability is useful for getting approximately the correct windowing, it is not adequate for telenuclear medicine interpretation.

Second, the browser can pass the data to a telenuclear medicine display application. In browser terminology, the display program is called a helper application. The display application can be a full function nuclear medicine workstation, or it can be a program with more limited image manipulation capabilities.

Third, a telenuclear medicine application may be sent along with the image data to the browser in the form of a Java program.[9-12] The advantage of this design is that

Table 1. Web Locations

ImageJ	http://rsb.info.nih.gov/ij/
ImageJ applet examples	http://www.med.harvard.edu/JPNM/ij/applets/parker.html
	http://www.med.harvard.edu/JPNM/ij/applets/Alignment.html
ImageJ DICOM plugin	http://www.iftm.de/produkte/dicomie/dcmie.htm
dcm4che DICOM package	http://dcm4che.sourceforge.net/
NucMed_Image	http://gamma.wustl.edu/caic/NucMed_Image.sea.hqx
Executor, ARDI	http://www.ardi.com/executor.php
Osiri	http://www.expasy.org/www/UIN/html1/projects/osiris/osiris.html
SeeMor	http://www.areeda.com/seemor/
Medview	http://www.medimage.com/
Mirage	http://www.segamicorp.com/
SMPTE test pattern	http://www.smpte.org/engineering_committees/medical.cfm
BWH test pattern	http://brighamrad.Harvard.edu/research/topics/vispercep/tutorial.html
Citrix	http://www.citrix.com/

no special equipment need be installed at the telenuclear medicine site. Any computer with an appropriate browser can be a full function workstation. Java is a computer language developed by Sun Microsystems Inc. (Santa Clara, CA), available on most computer systems and integrated into most web browsers. Although several computer companies promote it, the long-term viability of Java is less certain because Microsoft Corp. (Redmond, WA) is only reluctantly including it in its systems to meet its terms of a legal settlement. Java programs can either be run as stand alone applications, or they can be run as “applets” within a browser. Thus, the same program could be run in the department as a stand-alone application and at the telenuclear medicine site as an applet within a browser.

Slomka and coworkers reported on the implementation of a telenuclear medicine system using Java in 2000.[9] At the telenuclear medicine site, a web browser is used to access the nuclear medicine server. A patient study is selected from the mini Picture Archiving and Communications System (PACS) database, and then the image and the Java display program are downloaded to the web browser. The Java program allowed for several display functions, such as windowing, smoothing, and orthogonal view display. A commercial system, Hermes (Nuclear Diagnostics, Inc., Northfleet, Kent, UK), has incorporated this telenuclear medicine application.

ImageJ is a relatively small but capable, general-purpose, image-processing program written in Java by Wayne Rasband (Research Services Branch, National Institute of Mental Health). Table 1 lists the web locations for resources described in this article. ImageJ may be run as an application on any system that supports Java 1.1. (Easily installable, downloadable, free versions are available for Macintosh, Linux x86, and Windows). ImageJ can be run as a stand-alone system, or it can be run as an applet within a browser. The general-purpose display and analysis capabilities of ImageJ are supplemented by plugins, including radiology and nuclear medicine plugins written by a user community. ImageJ could be used as the workstation application in a telenuclear medicine application. Figure 1 shows an example web-based remote display, with an orthogonal view display of registered CT and fluorodeoxyglucose (FDG) data. Thomas Hacklaender has written DICOM import and export plugins for ImageJ, which are based on dcm4che, a DICOM package that includes network and archiving capabilities. Thus, a complete telenuclear medicine system could be constructed with relatively little effort from public domain Java-based software.

Other Viewing Alternatives

In addition to Java-based viewers, other home viewing solutions are available. NucMed_Image (by Mark Wittry, Software Only Solutions, St. Louis, MO) is based on the National Institutes of Health-Image program developed by Wayne Rasband. It can open a wide variety of nuclear medicine image formats, and provides basic nuclear medicine image viewing, adjustment, and cine capability. NucMed_Image is available free to Macintosh users, and can be run in a Windows environment using Macintosh emulation (Executor, ARDI). Osiris, a radiology-viewing program available for Unix, Macintosh, and Windows environments, is another freely available viewing program. These view-only programs need to be used with a separate file transmission capability. Commercial, third-party telenuclear systems such as SeeMor (Areeda Associates Ltd., Los Angeles, CA), Medview (MedImage, Ann Arbor, MI), and Mirage (Segami Corp., Columbia, MD) can also be purchased, and may include integrated patient selection and automated file transmission to the remote location.

BARRIERS TO IMPLEMENTATION OF TELENUCLEAR MEDICINE

Many nuclear medicine departments have gamma cameras of different ages from different vendors. It may be difficult to connect legacy systems to a telenuclear

Fig 1. Orthogonal view display by an ImageJ applet. In the background is a web page that is running the ImageJ display program as an applet. The main ImageJ window is the small rectangular panel in the foreground at the upper right corner. Buttons on the web page (visible at the lower left) were used to download a CT and emission fluorodeoxyglucose (FDG) data. The "Display Stacks" window in the foreground controls the orthogonal view display. The user selected the region of the carina on one of the views, and the corresponding orthogonal views from the CT and FDG studies are displayed with linked crosshairs.

medicine network. Special purpose, telenuclear medicine solutions have been designed to deal with these issues. However, these same problems are encountered connecting these systems to a PACS. Thus, it is often logical to combine the implementation of telenuclear medicine with implementation of a PACS.

The need for correlative imaging can also affect the ability to perform telenuclear medicine. The most common on-call nuclear medicine study, the ventilation-perfusion scan, cannot be read properly without a recent chest radiograph. Thus, even if an all-digital nuclear medicine division takes the lead in developing a system for on-call viewing, it is more difficult without similar progress in general radiology. Finally, hospital security concerns may adversely affect the ability to design an efficient remote viewing system, as is discussed in the section on security.

MONITOR QUALITY CONTROL

Quality control for monitors is an important issue for telenuclear medicine, particularly if the telenuclear medicine equipment is used for other functions. Major errors in interpretation can result from an improperly set up monitor. For example, if the remote computer is used for other applications, then one of those applications may change the display settings so that the nuclear medicine image is dramatically altered.

Less dramatic, but still diagnostically important, effects occur commonly due to the set up of mass-market computer displays. These displays often have increased contrast, which has the effect of background subtraction in low intensity regions and/or burning out of high intensity regions. Because these effects may be subtler, they may go undetected and adversely affect interpretation for a longer period.

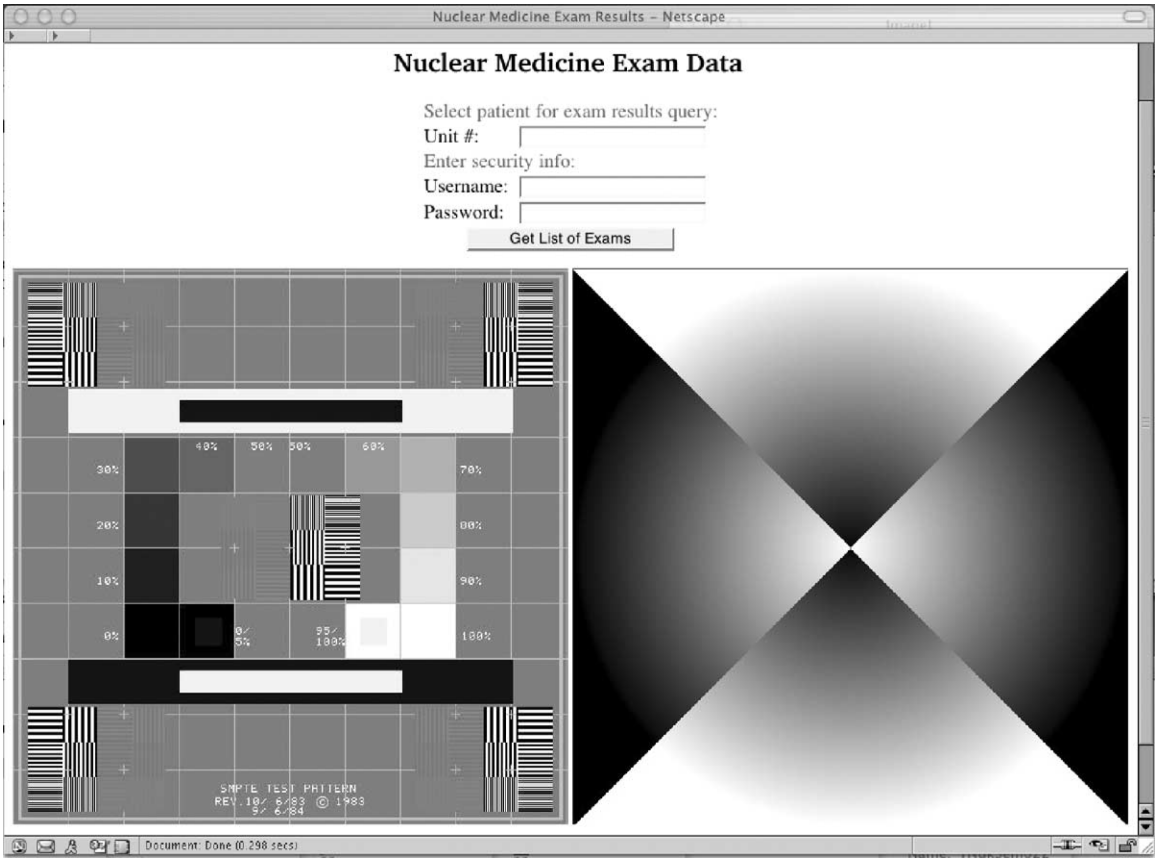

Fig 2. Telenuclear medicine system that starts up with test patterns. This telenuclear medicine system starts up with a SMPTE test pattern (Society of Motion Picture and Television Engineers SMPTE Recommended Practice RP 133 to 1991–Specifications for Medical Diagnostic Imaging Test Pattern for Television Monitors and Hard-Copy Recording Cameras) on the left and a Brigham and Women's Hospital (BWH) test pattern on the right. Monitor quality control is performed by the nuclear medicine physician with a quick check of these patterns.

There are sophisticated methods for image quality control on most high-end displays used in radiology workstations.[13] Many radiology departments have a regular schedule for quality control of these workstations. However, workstations designed for nuclear medicine generally do not include such high-end displays. There should be regular quality control of nuclear medicine displays, but, often, displays are adjusted on a more ad hoc basis.

There should also be regular quality control for telenuclear medicine systems. If the equipment is also used for teleradiology, then the radiology quality control should suffice for the nuclear medicine images. If the equipment is used principally for nuclear medicine, then the relatively simple measures described later can be performed with a minimum of time and effort. Quality control is highly simplified if the telenuclear system starts up with a display of image test patterns, such as the SMPTE Medical Diagnostic Imaging Test Pattern and the Brigham and Women's Hospital (BWH) test pattern (Fig 2).

Gray-Scale Linearity

One of the most important factors is linearity of the gray scale. Linearity can be checked using an image that has boxes of different intensity (eg, the SMPTE test pattern). The SMPTE test pattern has boxes that vary in intensity by 10%. These boxes should appear visually to represent equal steps in intensity. At the end of the scale, there is a 0% intensity box with a small 5% intensity box inside of it, and at the other end of the scale is a 100% intensity box, with a small 95% intensity box inside of it. The 5% and 95% boxes should be clearly visible. Problems with gray-scale linearity can frequently be corrected by adjusting the contrast and brightness settings on the monitor.

Gray-Scale Continuity

If the computer display or computer application is limited in the number of gray-scale levels it can display, artifacts can be introduced into the image caused by a noncontinuous gray scale. This problem commonly occurs when a computer monitor has been set to 8-bit color and can be made worse when there are several programs competing for use of the limited number of available display colors. In that case, there may be relatively few intensity values assigned to represent gray shades. The BWH test phantom has pie-shaped radial sectors of increasing and decreasing intensities. The pattern should appear continuous in intensity. A noncontinuous gray scale is detected by the appearance of circular rings or arcs in the pattern. A noncontinuous gray scale can frequently be corrected by selecting a gray scale only mode on the computer, or by selecting a video setting with a higher number of bits, often called "Millions of Colors" or "True Color." This mode gives 8 bits for each of the red, green, and blue color components, and allows the proper display of 256 gray levels. It is noteworthy that a setting of "Thousands of Colors" or "65,536 Colors" may be inadequate because a 5-bit red, green, and blue mode only allows for 32 levels of gray.

Resolution

Nuclear medicine images are generally not very demanding regarding resolution. Poor resolution is usually detected as blurring of small sized fonts before it causes difficulty with nuclear medicine images. The SMPTE pattern can also be used to test resolution. There are boxes with vertical and horizontal bars 1 and 2 pixels wide at the corners and in the center of the pattern. These bars should be visible without distortion or loss of contrast. In addition, the SMPTE pattern has low contrast, horizontal and vertical bars. Correlative images, especially chest x-rays have much higher resolution, and appropriate quality control of resolution for these images will be more than adequate for the nuclear medicine images.

Geometric Linearity

Nuclear medicine data are also not very demanding regarding geometric linearity. An adequate test of geometric linearity is to ensure that the various lines on the SMPTE test pattern are straight and that the boxes are square.

Bleeding or Ghosting

Monitors occasionally show an effect called "bleeding" or "ghosting," where a bright or dark portion of the image affects an adjacent portion of the image. This effect is more common with older television sets. It is less common with modern computer monitors. The long, white and black sections of the SMPTE pattern test for this effect. The test pattern needs to be rotated for monitors in which the scan direction is vertical.

Color

Quality control for color images in nuclear medicine is less well developed. The same quality control used within the department should also be used for the telenuclear medicine application. For example, the test pattern used within the department should look the same to the interpreting physician at the remote location.

SECURITY

Allowing access to nuclear medicine systems for home use may increase the risk of unauthorized access. This penetration of a nuclear medicine system can take 1 of 2 forms.

Access of Confidential Data

Nuclear medicine is a relatively low profile target in this regard. However, the data, including that a procedure was performed, are confidential medical information. Thus, it is prudent to use secure communications. Fortunately, the usual Internet security (ie, https) with individual login and password protection should be adequate if a web-based telenuclear system is used. If the telenuclear medicine site is accessible to nonauthorized users, then it is reasonable to implement a time-out mechanism on the telenuclear medicine application. The unnecessarily burdensome security requirements of the federal Health Insurance Portability and Accountability Act (HIPAA) are still being finalized, but they have increased awareness of the need to protect patient information in radiology systems and may, therefore, have some useful effect at those sites that have not previously given any consideration to system security. If files with patient information are transmitted off-site, this may need to be incorporated into your HIPAA compliance program.

Compromise of Computing Systems

Unfortunately, this risk is high for any computer with direct connection to the Internet, as many can, unfortunately, attest. Many of the computer operating systems in use today have security holes in them. Fixes for these holes are issued by the use of frequent operating system "patches," but it is difficult to keep all systems up-to-date. Furthermore, nuclear medicine vendors may have received Food and Drug Administration approval to run their software only on a specific (older) version of the operating system, preventing them from installing security patches as they become available. For this reason, it is critical that the nuclear medicine computers in the department be separated from the Internet by some sort of protective device, usually referred to as a "firewall."

A firewall is a specialized computer that blocks most access from external computers, allowing access only from approved sites using specific network protocols. Internet access through a firewall should use a network protocol that provides for encryption of passwords and data, such as a Virtual Private Network. Secure data servers, such as Citrix, are also available to send data from Windows servers to home computers, which can be either Windows or Macintosh based. Some remote teleradiology systems avoid the Internet entirely and use a (more expensive) direct digital telephone connection known as Integrated Services Digital Network. Although such a connection is slower than a high-speed Internet connection, it is still several-fold faster than a 56K modem connection. Whichever method is chosen, it is important to consider system security in the design of a telenuclear medicine system.

MULTIHOSPITAL SHARING OF CALL COVERAGE

Expert nuclear medicine physicians are sparsely distributed. Even large groups have relatively few experts available to share call. Although emergency studies can be very valuable, there are at most a few studies in a single day. Telenuclear medicine ameliorates this problem somewhat because the time needed to interpret an emergency study becomes similar to the time required for routine studies. However, call still places a relatively heavy, availability burden on the expert.

Telenuclear medicine provides the hope that call could be shared among a wider group of physicians. The Internet makes it feasible to share call with physicians in other parts of the world, so that call can be shifted to working hours. There are many organizational and legal issues that need to be overcome to set up such a system. The major technological issue is providing a common user interface across systems used in different health care facilities. However, Internet-based telenuclear medicine has hope for the more efficient delivery of on-call expert interpretation.[14]

CONCLUSIONS

Many types of remote viewing systems are available in nuclear medicine, with a wide range in functionality and cost. The quality control of remote telenuclear medicine monitors is important to accurate diagnosis. Relatively simple test procedures are adequate to test monitors that will be used for nuclear medicine interpretation. If the telenuclear medicine application starts up by displaying test patterns such as the SMPTE and BWH test patterns, the nuclear medicine physician can quickly identify important problems with monitor quality control. Timely, expert interpretation of emergency nuclear medicine studies is possible using currently available telenuclear medicine systems. The continued development of these systems holds promise for making expert on-call interpretation even more efficient.

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