Interpretation and Reporting of Myocardial Perfusion SPECT: A Summary for Technologists*

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Interpretation of cardiac perfusion SPECT images, and the subsequent reporting of results to referring physicians, are sometimes taken to be outside the sphere of the nuclear medicine technologist. However, all personnel involved with nuclear medicine procedures contribute to the timeliness and usefulness of the final report. The goal of this article is to review the principles of scan interpretation and reporting, from the standpoint of what technologists need to understand about these processes. In addition, software tools to aid these processes will be discussed, including quantitative image analysis, telemedicine, computer-aided scan interpretation, databases, computer-aided reporting, and Internet-based reporting. Finally, the accuracy of the scan report will be related to the tasks normally performed by technologists, such as the acquisition and processing of images and the entry, transfer, and networking of data. After reading this article, the reader will be able to describe the principles of scan interpretation and reporting, the software tools for telemedicine and computer-aided interpretation, and the role of the technologist in this process.

Key Words: myocardial SPECT; image interpretation; expert systems; neural networks; Internet

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The system of patient admissions and referrals currently in place in many institutions is geared toward high patient throughput. Patients experience minimal hospital stays even for surgery, myocardial infarction, or congestive heart failure. Because of the pressure to keep the whole process moving forward, cardiologists are exposed to a large volume of data about every patient. In addition to history, symptoms, electrophysiology, chemistry, and pathology are the results of various imaging studies. In the nuclear medicine laboratory, patients undergo cardiac perfusion SPECT studies, which also generate a large amount of varied information that has to be integrated into the patient's overall clinical picture. As expressed by one author (*1*), "The pressing issue often is time rather than in-depth knowledge acquisition." There is a need for practices and specific tools that allow efficient interpretation of nuclear images without loss of the depth of information that today's imaging protocols offer.

The various pressures currently at work in the nuclear cardiology laboratory have stimulated advances in at least 3 areas. First, new software tools are available or in development to increase the efficiency of image interpretation without sacrificing accuracy and confidence. Second, the last few years have seen an initiative to codify the elements of a standard report for cardiac perfusion studies. The third advance is the development of hardware and software to streamline reporting. This seems an appropriate time to review how cardiac SPECT images are interpreted and reported, to summarize new developments, and to consider the technologist's role in the process.

HOW CARDIAC PERFUSION SPECT STUDIES ARE INTERPRETED

Who Interprets Nuclear Cardiology Studies

In different institutions, nuclear cardiology studies may be interpreted by cardiologists, radiologists, or physicians who work full time in nuclear medicine. The Nuclear Regulatory Commission has certain requirements for physician licensure, but these are based primarily on radiation safety concerns, not clinical proficiency. The Joint Commission on Accreditation of Health Organizations mandates that an institutional mechanism be in place for determining the interpretation privileges of staff members. Institutions can develop their own mechanisms; however, specific guidelines for the performance of clinical nuclear cardiology studies and for the training of physicians to interpret them have been published by the American College of Cardiology, the Society of Nuclear Medicine, the American Society of Nuclear Cardiology, and the World Health Organization. In 1997, Sorrell and Reeves (*2*) undertook a survey to determine the extent to which these guidelines were being used in 80 medical institutions in the United States. They found that approximately 3 of 4 institutions allow cardiologists to interpret nuclear studies, whereas the remaining institutions use solely radiologists or nuclear medicine phy-

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sicians. Moreover, 3 of 4 institutions require at least 4–6 mo of specific training, which is in line with the guideline of the American Society of Nuclear Cardiology and the American College of Cardiology for persons in formal cardiology programs. The number of studies read by cardiologists has been steadily increasing since 1991 (*3*).

Elements of Interpretation

The interpretation of any medical image breaks down to a simple theoretic process: identifying the image pattern and classifying the pattern. In myocardial perfusion SPECT, the pattern consists of count intensities in the left ventricular myocardial images. It is assumed that relative tracer uptake in the myocardium directly correlates with the blood flow that is available to each area of tissue. The process of interpretation could take place in many ways, but all have 2 fundamental steps in common: The reader first recognizes the perfusion pattern and then classifies the pattern by diagnosis and prognosis (*4*). An experienced reader will have a mental template for what constitutes normal findings. In a typical method of interpretation, the physician first identifies the finding, which consists primarily of the myocardial perfusion pattern. This might be done by looking at the SPECT oblique slices. Once the reader has established that the study under review does not fit the normal pattern, the findings must be interpreted, since the pattern may be the result of known disease, new and unsuspected disease, or an artifact. At this point, the physician might choose to look at parts of the imaging study that would help identify an artifact, such as the planar projections. If no artifact is present, other elements of the study can be assessed for corroborative evidence of true disease. Additional image findings such as an enlarged left ventricular myocardium, a change in left ventricular size from stress to rest, a prominent right ventricle, and the presence of tracer uptake in the lung can corroborate true disease.

One important element is the stress test result, which can help the reader determine whether the perfusion defect is due to significant disease. If the disease is believed to be real, the perfusion abnormality can be characterized by defect size; defect severity; defect location, including the likely culprit coronary vessel; and the presence or absence of a reversible pattern. If one or both parts of the study are electrocardiography gated, then left ventricular function can also be assessed and quantitated. These results can further illuminate the question of disease versus artifact.

Another approach to interpretation involves an orderly progression through the available images, starting with the rotating planar projections. These images can show patient motion, shadows due to attenuation, and high-count extracardiac structures, all of which foreshadow problems with interpretation. Having a good idea of the quality of the data acquisition, the reader proceeds to the oblique slice images and identifies the perfusion pattern. Review of quantitative results and polar maps follows. If the slices and quantitative results are discrepant, further investigation is needed. Finally, the functional values, gated cine results, and stress test results are reviewed.

Often, the study is read twice. The first time through, the physician is unaware of the clinical data (except for patient sex), in order not to bias the reading. After this thorough interpretation, the study is briefly reviewed again, and additional available information is considered, such as the patient's history, the results of the stress test, and the results of other diagnostic tests such as cardiac catheterization. This second interpretation may clarify the perfusion pattern in equivocal areas and, by making possible an interpretation that is more clinically relevant, also prepares the reader to interact with the patient's physician. In the outpatient setting, it is particularly useful to include in the report what is known about the patient's clinical condition, to minimize misunderstanding of the report (*5*).

Simons et al. investigated the impact of knowledge of clinical data on interpretation of thallium SPECT and found that this knowledge resulted in a change in interpretation in 27% of cases (*6*). In 8% of cases, the change was major. This change occurred more often in patients with suspected coronary disease than in patients whose disease was already documented. Simons et al. also found that radiologists and clinicians sometimes interpreted the clinical information differently. The same clinical data could be used twice: once by the nuclear medicine reader to influence scan interpretation, and again by the clinician to evaluate the significance of the scan report in terms of prognosis and patient management.

Agreement between the interpretations of different observers has been shown to be good, even at different institutions, when a uniform method of displaying the image data is used (*7*). Agreement depends somewhat on the experience of the interpreters (*8*).

The Role of Quantitative Analysis

Although not universally used or accepted, quantitative analysis (or "quantitation") in perfusion SPECT offers several potential advantages. Quantitation attempts to provide a more in-depth analysis of perfusion patterns than does visual interpretation alone and, as such, could help maintain the competitive balance between nuclear cardiology and other modalities, all of which are becoming increasingly sophisticated. Quantitation, because it is objective, provides reproducible results and an unbiased "second opinion" to the human interpreter. Quantitation can call attention to myocardial regions that might need closer scrutiny and allows greater confidence in the visual interpretation. Visual reading of oblique slice images can differ from quantitative results. Investigating these discrepancies often leads to greater understanding of the images.

Quantitative analysis, as implemented in currently available commercial software, offers many options. Myocardial perfusion can be quantitated and compared with predefined reference limits, and the results can be displayed automatically in terms of the number of abnormal pixels, the percentage of myocardium, the number of grams of defective myocardium, or the total number of SDs below the normal mean for all defective regions. These values can be given per defect or per coronary territory. Once the values are calculated, they can be presented in table form or as bar graphs or can be plotted pixel by pixel as color polar maps. Some programs allow the user to vary the threshold of normal or to see which areas of the polar map correspond to which short-axis slices. Various quantitative options are intended to help the physician understand nuclear images more thoroughly, but the number and variety of these options sometimes threaten to overwhelm the less experienced interpreter with calculated values and alternate ways of looking at the same images. This is where tools to aid interpretation become useful.

NEW TOOLS FOR AIDING INTERPRETATION

Enhanced Computer Display

Existing computer displays of image data can be enhanced in several ways for interpretation and reporting. The easiest enhancements involve the location, flexibility, and multipurpose use of display terminals. For example, a practical way of serving the users of nuclear cardiology is to place a computer terminal in the patient care area. In this way, image results can be shared with clinicians when they are making their rounds, either to present a preliminary report or to display images after a detailed report has already been given. In this setting, images can have a greater impact than can a printed report alone (*1*).

Computer displays will serve multiple purposes, such as text-intensive data entry and graphic-intensive display of widely varying kinds of radiologic images. Today, one can view gated MR images on the same screen that displays gated SPECT results. Options on image display software are being enhanced to provide more flexibility, such as streamlined review modes and user-configurable review screens.

Telemedicine

Images can be interpreted by individuals outside the imaging setting. Previously, such interpretation was accomplished by mailing films or hand-carrying computer media, but image transfer is increasingly being done by telemedicine. The images can be transmitted to a remote site electronically and interpreted by experienced physicians, and the interpretation can be sent back by fax or by an encrypted electronic file transfer protocol. Images can also be made available to the remote site through the Internet, without actually being transferred to another computer, and the interpretation can be made online. The main advantage of the telemedicine approach is that it brings experts to the patient instead of requiring the patient to go to the experts. In principle, telemedicine is an expansion of the local area networks that many institutions already have in place (*9*).

Several challenges exist for telemedicine. Setting up and maintaining the network represent an economic challenge. Optimizing the speed and integrity of data transfer, which is an issue for both the hardware and the software of both the originating and the receiving computers, is also a challenge. Establishing connectivity between images from different platforms can be challenging: It is important that the Digital Imaging and Communications in Medicine (DICOM) format mature into a fully usable standard for all types of nuclear medicine studies and that the DICOM implementation of different vendors be as compliant as possible with standards. Another challenge is the legal issue of maintaining the security and confidentiality of patient data during transfer between computers in a local or wide area network. The final challenge is communication: The interpreter needs to know whether quality control tests of hardware and acquisition have been performed and whether patient-related issues such as body habitus or inadequate stress are present, and the referring physician needs to know the expertise of the interpreter and which software was used for additional image processing.

We can expect opportunities for telemedicine to expand to the scheduling, reporting, and archiving of imaging studies, perhaps by different departments within an institution (*10*). Users will have an enhanced ability to reconstruct and process images by issuing commands across computer networks (*11,12*). Some institutions have already introduced the concept of the electronic medical record, allowing access to comprehensive patient information by local area network or Internet. This information includes demographics, test results, images through a link to Picture Archiving and Communications System (PACS) servers, and tools for filing and cross-referencing information and documenting communications between individuals involved in patient care. How well these sophisticated technologies will interact with one another remains to be seen.

Decision Support Systems

Decision support systems either aid the physician in interpreting image patterns and the significance of study results or provide an independent image interpretation that the human reader can consult. These systems fall into several broad categories, depending on the underlying methodology: the artificial neural network (ANN), the expert system, and case-based reasoning (CBR).

ANNs

ANNs are an attempt to mimic, using software, the operation of biologic neural networks such as the human brain. Like the brain, the ANN is made up of several layers of nodes, or calculating elements. The ANN nodes are individual software routines that are extensively cross-connected and are analogous to neurons in the brain. Analysis of the input data proceeds from one layer to the next, and there may also be connections between layers for feedback or "feed-forward" of information. Because of its structure, the ANN can become adept at pattern recognition, like the human brain. The ANN must be trained to recognize patterns by being exposed to examples of all of the many patterns it is likely to encounter. The performance of the network is adjusted by comparing its results to a gold standard. In nuclear medicine, ANNs have been applied to such essentially pattern-matching tasks as the interpretation of nuclear lung scans (*13*) and to more involved tasks such as the interpretation of cardiac perfusion studies by planar (*14*) and PET (*15*) methods.

One example of ANN-based automatic interpretation of myocardial perfusion is the WeAidU system (*16*). Because image interpretation by humans varies between observers, a computerized system that will use human interpretation as a gold standard should be tested at multiple institutions. In a recent European multicenter trial of WeAidU (*17*), perfusion studies were transmitted from 4 different hospitals to the ANN system through the Internet, along with a detailed physician interpretation of regional perfusion. The ANN then made its interpretation, and the 2 interpretations were compared. Agreement with the physician was good, varying by hospital from 74% to 92%.

The ANN is somewhat of a black box, in that the human user does not know, and the system cannot explain, how its solution was arrived at. However, the approach is promising because the system—again, like the biologic neural net—can learn from continued experience.

Expert Systems

The expert system uses a set of rules to interpret a study. The rules are initially derived from systematically breaking down the process that a human expert goes through in interpreting a variety of studies. Individual rules take the form of if–then statements (and there may be a large number of these), with many of them taking a compound form such as "if A and B then C" or "if A but not B then C." When a certain rule comes into play, the rule is said to fire, and firing may cause certain other rules to become available or unavailable. One advantage of this approach is that when the system presents its interpretation, it does so with a particular quantitative certainty related to how many rules fired and which rules they were. Thus, the system can extensively explain and justify its conclusion by referring to the rules it has used. A commercial expert system (PERFEX; Syntermed, Inc., Atlanta, GA) is available for myocardial perfusion SPECT (*18*). This system can perform its interpretation at one of several points on the receiver operating characteristic curve, so that it can easily be set to read the study with high, intermediate, or low sensitivity (Fig. 1).

CBR

Like the ANN and the expert system, the CBR system approaches the study interpretation task as would a human. In one published CBR system (*19*), a computer algorithm compares myocardial perfusion results from a particular study with a large number of example cases stored in its

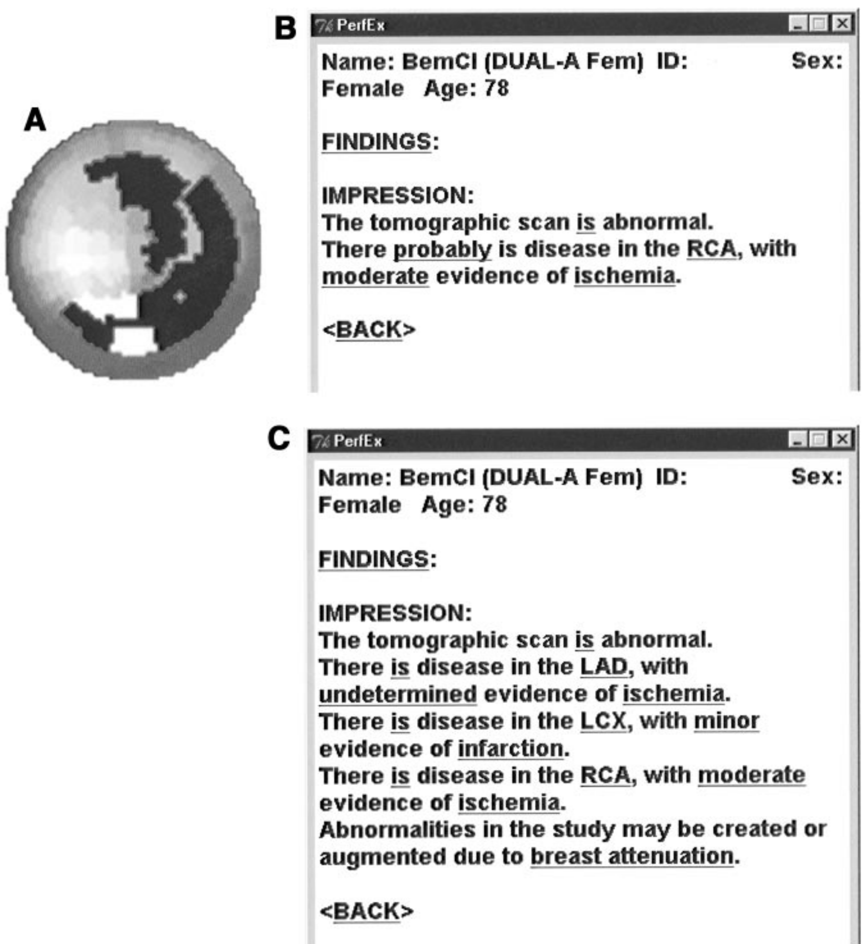

FIGURE 1. (A) Polar map with perfusion defect extent shown in black and significant reversibility within defect shown in white. Two possible expert system interpretations for patient are shown. System can be instructed to read study with high specificity for abnormality (B) or with high sensitivity (C). At high-specificity setting, only areas with greatest certainty of abnormality are included in impression. As is always true, higher sensitivity implies lower specificity, and vice versa. Setting might be changed depending on clinical question being asked. In these windows, which are displayed to user, each underlined word is a hyperlink that, when mouse-clicked, displays more text to explain interpretation.

internal library. Each library case includes a formal description of the tracer distribution, along with associated items such as angiography results. The CBR system collects studies that match the current study, calculates the degree of match, and predicts the outcome (angiography results) of the current study on the basis of these library cases. Such a system could explain its solution by way of example and could use a preexisting database as its case library, provided the outcome data are present and the database format is compatible with the CBR program.

Data Mining

Data mining is the systematic analysis of data, in particular the associations between data items, with the goal of inferring new knowledge about the nature of the data. Though not a technique that is applied to image interpretation per se, data mining has been used in various nonmedical applications for years and seems applicable to the large volume of data generated in even a moderately busy nuclear cardiology department. The new knowledge gained by mining existing data could potentially be used to "recalibrate" human or computer-based interpretation of future nuclear studies. Preliminary work has already been done in this area (*20*).

HOW CARDIAC PERFUSION SPECT STUDIES ARE REPORTED

Defining the Nuclear Report

Reporting is not the same as interpretation. The report is an official summary of the interpretation and becomes a part of the patient's medical record. In the past a printed report was inserted into a file folder, but some institutions are already moving toward electronic medical record systems. Hard copies of images can be appended to a physical report, which is given to the referring physician.

The nuclear cardiology report is the tangible end product of the entire study. In practice, institutions and individual physicians prepare reports according to their own preferred style. This naturally leads to variation in both form and content of the report, even though the basic elements are always present. Unlike the steps that influence image creation (quality control, acquisition, reconstruction, and quantitation), there has been little effort to standardize or to assess the quality of reporting, until recently. The Intersocietal Commission for the Accreditation of Nuclear Medicine Laboratories (ICANL) has published report templates suggested for several different nuclear cardiology studies, noting in the process that the nuclear report serves 2 purposes: to communicate to the referring physician the results of the stress, perfusion, and function studies performed and to document for reimbursement purposes the services that have been provided (*21*). In addition, the American Society of Nuclear Cardiology has published a position paper on mobile and remote-site nuclear cardiology services that includes image interpretation and clinical reporting (*22*).

In addition to the factual content of the nuclear cardiology report, the way the information is presented can help ensure that the bottom-line message is conveyed efficiently and without misunderstanding. Because the important elements of a report are always the same, many departments use a formal template. For example, the template could be organized into the following general sections: patient demographic information, radiopharmaceutical dosing information, stress test results, description and interpretation of images, and final impression.

An organized report is adhered to even if no formal template is used, because physicians find themselves repeating the same phrases and conclusions in many reports. Consistent organization makes the report easier for the interpreting physician to prepare and for the recipient to follow.

Elements of the Nuclear Report

Scan interpretation includes several considerations. Some are specifically mentioned in the report, but many are not. Here are examples of such considerations, showing which might be included in a typical report:

Included: the reason that the test was done. *Not included:* medication history, other symptoms, or prior diagnostic tests, unless they relate to the reason for the present study. Pretest likelihood of disease may be calculated but is not generally included in the report.

Included: succinct details of stress, radiopharmaceutical administration, and image acquisition, including notation of whether the patient had adequate exercise stress or pharmaceutical-induced vasodilation. *Not included:* specific acquisition parameters or noncardiac side effects experienced by the patient after pharmaceutical stress, unless significant.

Included: image quality, noted using terms that may be as simple as "excellent/adequate/suboptimal." Camera quality control problems or other technical limitations such as patient motion on only one part of the study could be noted in the report, particularly if additional imaging is to be performed later. *Not included:* image processing details, such as filter settings.

Included: assessment of overall study quality. Not infrequently, an artifact cannot be ruled out as a cause of a perfusion defect, and the report will state this fact. Although this practice is good from the legal perspective, interpreters try to avoid excessive use of hedge statements, because they make the report less helpful to the referring physician. In distinguishing between artifacts and real disease, one uses all parts of the study: Wall thickening is assessed on gated slice cines, attenuation and motion are observed on planar projections, and oblique slice images are studied for signs of motion or poor count density. *Not included:* camera quality control verification.

Included: assessment of perfusion defects. Today, this often includes an opinion as to the vascular territory that is associated with the defect. Knowledge of the patient's coronary anatomy from angiography can enhance the usefulness of the nuclear report. If multiple stenoses are seen at catheterization, the culprit lesion can often be identified by matching its territory to the perfusion defect on the nuclear scan. With current software, the size, location, depth, and degree of reversibility of perfusion defects can be quantitated so that the amount of myocardium at risk can be determined. *Not included:* complete listing of quantitative results.

This list is an example (*23*) and would be slightly different for different laboratories. Some interpreters might consider certain "not included" items to be "optionally included." Given the amount of quantitative information that can be generated by quantitative analysis software, the interpreter must decide which values to report. This is a function of the individual reader's confidence in the computer software and is also guided by the specific clinical question that the scan is trying to address. Often, the calculated values that relate to or support the report's conclusion may be reported.

Handling of the Report

In the traditional approach, a verbal report is dictated by the physician and recorded on tape. The tape is then transcribed by another person into a written version, which is returned to the physician for his or her signature. The report must be signed by the physician who dictated it, and the signature indicates that the report is final and is suitable for adding to the patient's permanent record. Then, the report can be filed and a copy can be distributed to the referring physician. If any additions to the report are needed, a separate addendum must be dictated and sent through the process described above. An addendum might be prepared, for example, if additional imaging is performed that is considered part of the same study. All of these steps take time. Several parts of the process could be streamlined or eliminated by the use of new electronic tools or by the novel use of existing tools. One of these tools is the computerized database.

Databases

Databases can be "flat file" or relational. The flat file is the traditional database consisting of records, each having multiple data fields. The relational database adds the ability to relate each record to many other records, which may be held in separate databases, by means of unique key fields. The various elements that might be included in the nuclear cardiology report can be entered into their respective databases at different times, by different personnel. For example, the scheduler might enter the patient demographic data, and then later the technologist would enter the radiopharmaceutical dose injected. It is useful to have methods for maximizing the correctness and completeness of the database, including redundant fields for cross-checking data items entered by different personnel, options to define critical fields and to determine when these are missing, and checks for inappropriate data values, such as pharmaceutical doses or physiologic parameters that are outside the expected range.

Today, a significant portion of nuclear cardiology studies are done in outpatient facilities, including physician offices. These facilities benefit in efficiency from using a database of both clinical and business information. With today's managed care initiatives, it is important to be able to demonstrate the cost-effectiveness of a procedure. In addition, assessment of patient outcomes is an increasingly useful tool for justifying third-party payer reimbursement and for demonstrating the power of nuclear cardiology procedures for prognosis. Clinical and business goals are easier to achieve if the relevant information is entered into an ongoing database, which can be augmented with the results of therapeutic and nonnuclear diagnostic procedures and with case follow-up. Use of the relational database model can reduce redundancy in stored data and help to streamline the process of cross-referencing follow-up studies and test results from different modalities (*24*).

With the advent of networked computers, electronic medical records, and telemedicine, it will be important for the database to generate files in a format that is accessible for uses outside the database program itself. Finally, the database contains personal and confidential patient information and must be maintained on a secure computer, with adequate identity authentication for any person accessing that computer, and there must be a reliable means of ensuring data integrity during transfer to another computer. Large, mostly textual databases, usually referred to as radiology information systems, also will need to integrate with image databases, or PACS systems (*25*), to ensure the success of electronic medical record systems. Some institutions have already begun to implement electronic medical systems.

NEW TOOLS FOR AIDING THE REPORTING PROCESS

As we have seen, the nuclear report is an organized document that is expected to contain certain elements. So it is not a big leap to accept that automated programs could be used to help generate reports. A simple form of automation is a dictation system that uses voice-recognition software to generate printed text (*26*).

As discussed above, a database holds patient information that would routinely be included in the report. Ideally, reporting system software could extract this data automatically when the final report is to be generated. An automated reporting system would be particularly welcome if it helps reduce time-consuming steps such as retrieving previous study results, obtaining the results of other tests, and obtaining information previously entered into another computer, such as pharmaceutical doses. Smaller institutions such as cardiology group practices or private offices might be motivated to use the automated report tool. In this setting, the nuclear report is often closely integrated with patient management decisions, so there is a need for fast turnaround and focused, relevant reporting. It is potentially easier to integrate the automated system in a small institution, where databases are typically under the control of only a few individuals, or perhaps just one. Large institutions have various departments that are independent and have different personnel who may be using very different database models, software, data formats, and computers. Certain departments may be unwilling or unable to contribute to the expense of establishing the networking hardware necessary for speedy data-sharing. They may also be reluctant to give up their own established protocols and formats or to share the data that they have spent many work-hours entering into their own systems. These are some of the hurdles that need to be overcome before automated reporting becomes pervasive. Nevertheless, several software solutions have already been developed to aid the reporting process. We will examine several examples of these.

One system, developed at the University of Maryland (College Park, MD) (*27*), uses a report template and allows the reader to access text segments from a standardized list of segments that were found to occur commonly in reports of normal and abnormal findings from clinical studies. The program makes available lists that are sensitive to the context of the report and can be customized as necessary for improved flexibility. Links are provided for access to various interpretation aids, including reference ranges for numeric values, diagnostic criteria, billing codes, and live Internet resources such as MEDLINE (U.S. National Library of Medicine, Bethesda, MD).

A comprehensive report-generating package is Nuclear Report Professional (NRP) (POSMEDIC LLC, Atlanta, GA, in conjunction with Syntermed, Inc.). This system was built using a commercial relational database program (4D, Inc., San Jose, CA). As shown in Figure 2, the user can track all aspects of the study. For day-to-day reporting, user interface controls define the various items that would be included in a standard report: imaging protocol details, electrocardiography results, interpretation of perfusion, segmental wall motion, etc. A system such as this can be used to create a database of many study details that may not be used in the physician's report but that might be useful for other purposes, such as scheduling of procedures, medical research, tracking of referral patterns, or analysis of business efficiency in a small medical office.

NRP can read text and image files that have been created by a nuclear cardiology software package. The reporting system provides an opportunity to change the 20-segment visual perfusion scores using imported polar map images (Fig. 3), even if the software is running on a remote computer. The creators believe that the ability to interact in this way with nuclear systems and their output files will be an important tool for users of automated reporting systems.

The Internet is a natural avenue for disseminating information, and we might expect to improve the efficiency of interpretation and reporting of cardiac SPECT images by electronically transmitting images and clinical information from one location to another. Indeed, the necessary tools

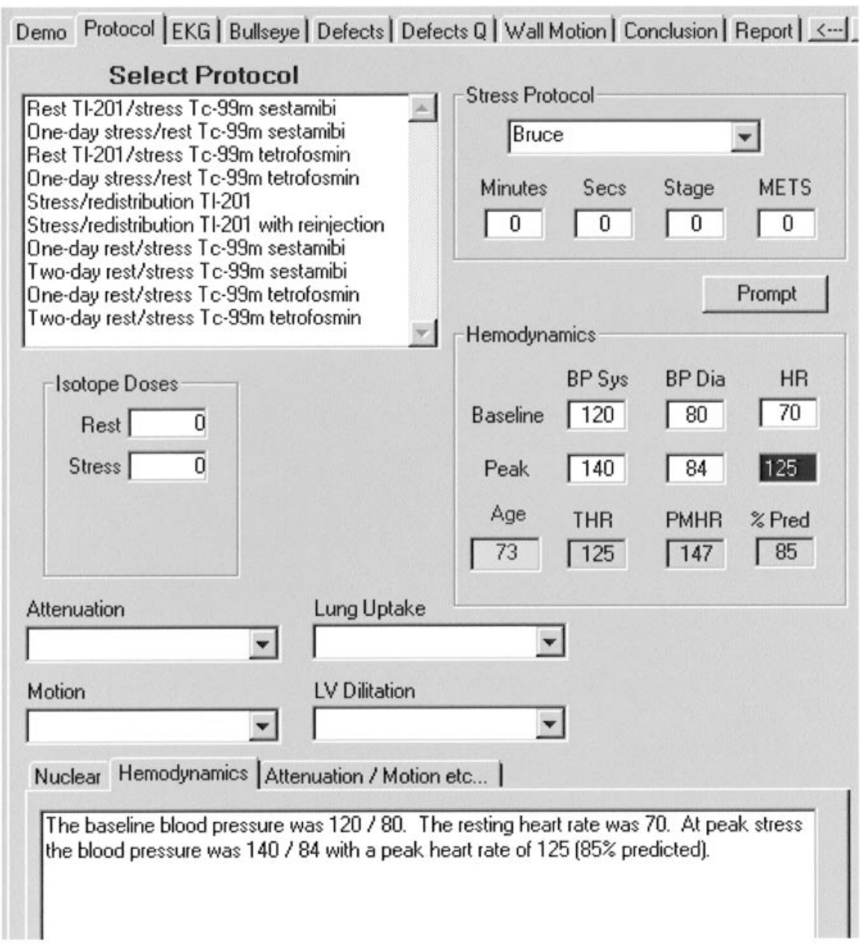

FIGURE 2. Example from NRP showing part of 1 interface tab. This tab allows reader to define stress protocol. As hemodynamic values are entered, textual report is built up, as shown in window at bottom. This text will become part of final printed (and entered in database) report, if user wishes.

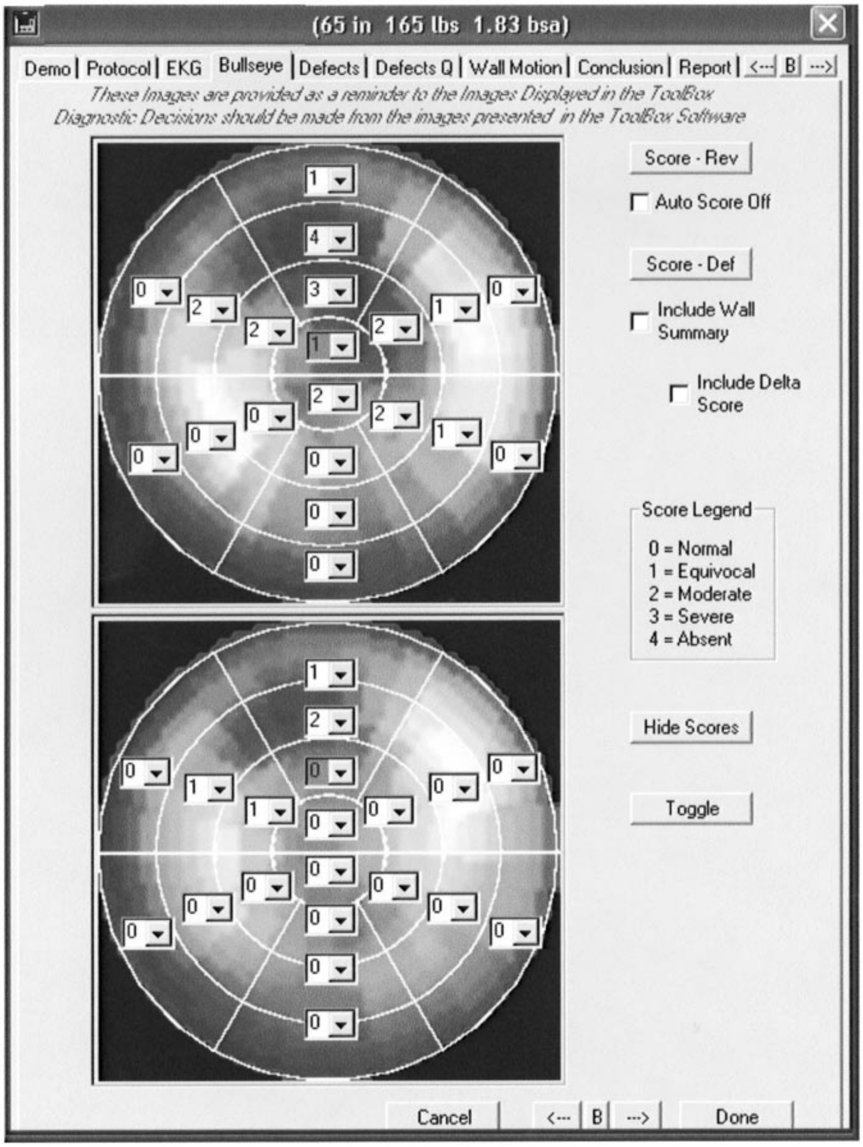

FIGURE 3. Screen within NRP, showing polar maps imported from nuclear medicine workstation. In each of 20 myocardial segments, perfusion scores that were originally assigned are shown in boxes with white backgrounds. Numbers in shaded boxes are those that physician using NRP has decided to change.

have existed for several years: namely, a database, an Internet browser, and software to view images. Routine use of image transmission has become practical with the advent of fast network connections. An Internet solution for either image processing or study reporting is efficiently implemented using the client–server model. One central computer serves files to several client computers at remote locations. The software to perform specific operations on the images resides on the server and is downloaded to the client only when needed. Having a single version of the application makes supporting the software easier, while allowing updates to be made available more quickly and transparently to the user. A diagram of the general client–server system is shown in Figure 4A. Of course, any server exists in a larger networking context and must interact with systems at various levels in order to be useful. A general example of an overall network is shown in Figure 4B.

One example of a remote reporting package was developed at Guy's and St. Thomas's Hospitals (London, U.K.) (*28*). In this tool, Interfile (The Keston Group Consulting Inc., Edmonton, Alberta, Canada) images are converted to a DICOM-compatible format, from which details are extracted and entered into a database that responds to Structured Query Language (SQL) commands. The database exists on a secure server computer, to which a client computer can connect from any location. A World Wide Web interface allows the user to specify the desired information, which is passed to an underlying search engine that generates an SQL query that is handed to the server. The server passes the query to the database, and the client downloads a report that is partially filled out, along with the corresponding nuclear images. The freeware image viewer Osiris (University Hospital of Geneva, Geneva, Switzerland) is used as a browser helper application, allowing display of nuclear images on the client's own machine.

Another instance of the Internet-based approach is the Java-based Remote Reporting and Viewing Station (JaRRViS) package developed at the University of Western

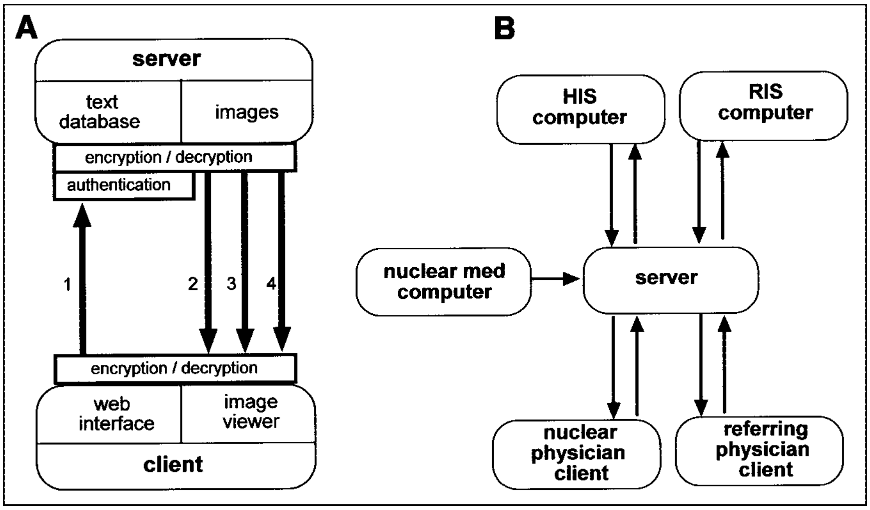

FIGURE 4. (A) Client–server schematic. The 4 illustrated types of information transfer are database query (1), download of software (2), download of database data (3), and download of images (4). SQL database on server is for storage of patient records. Image viewer may be as simple as a plug-in for a Web browser or may be an independent program such as Osiris (University Hospital of Geneva, Geneva, Switzerland). Likewise, Web interface may be a standard Internet browser or a more specialized program. (B) Environment in which software server exists. Hospital information system (HIS) and radiology information system (RIS) computers may impose their own security layers and information format requirements. In addition, nuclear medicine computer must be able to provide images in standard format, which at present means either DICOM or Interfile.

Ontario (London, Ontario, Canada) (*29*). Java is a programming language that is essentially independent of computer platform and has become widespread in Web-based applications. The general scheme for this system is shown in Figure 5. In JaRRViS, executable programs and color tables are transferred to the client computer on request, after authentication of the user's identity. The user can perform typical image manipulations such as window level adjustment, spatial smoothing, dynamic cine display, and comparison of images from more than one study. The reporting module allows selection and annotation of images and generation of a multimedia report that can be saved to the patient's electronic folder in HyperText Markup Language (HTML), optionally with voice-recorded notes. An HTML file can be displayed with any Web browser. Figure 6 shows an example JaRRViS report, as viewed by browser software. The system uses both applets and "servlets." Applets are Java programs that are downloaded to the client computer when needed for a specific task, after which they disappear, whereas servlets are programs that run on the server computer and remain there.

THE TECHNOLOGIST'S ROLE

The technologist has no direct role in image interpretation and reporting. However, many of the duties of the technologist will have a bearing on these processes. The process of interpreting myocardial SPECT is simple in theory, but the interpretation may be challenging because of several diverse factors, such as patient body habitus, camera performance, and radiopharmaceutical dose delivery.

High-quality acquisition and processing are prerequisites to high-quality output, and these depend primarily on the nuclear technologist. If care has been taken with these steps,

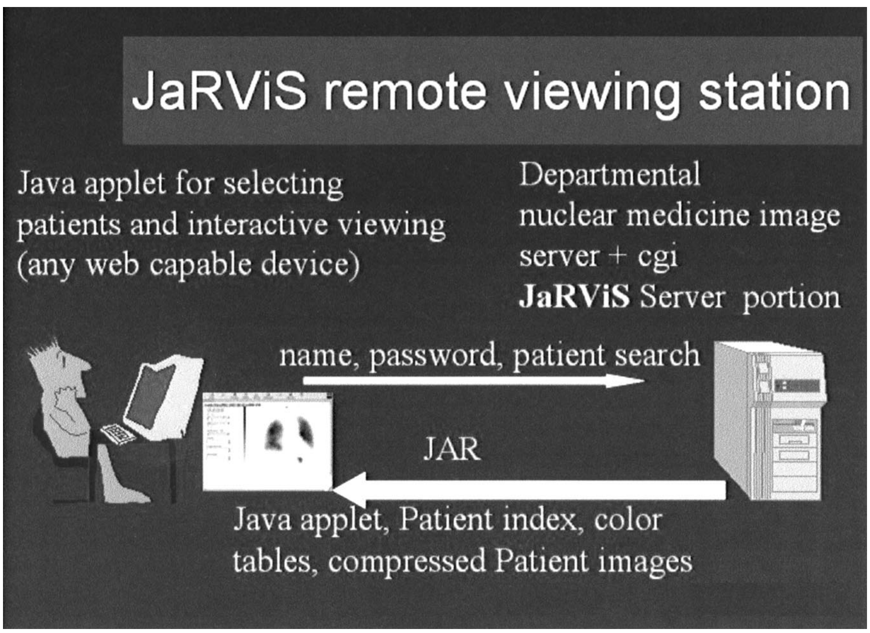

FIGURE 5. General scheme for JaRRViS (previously known as JaRVis). *JAR* refers to Java archive, which contains applet and associated files. *cgi* means common gateway interface and refers to small programs that run on server machine, often for handling user interaction.

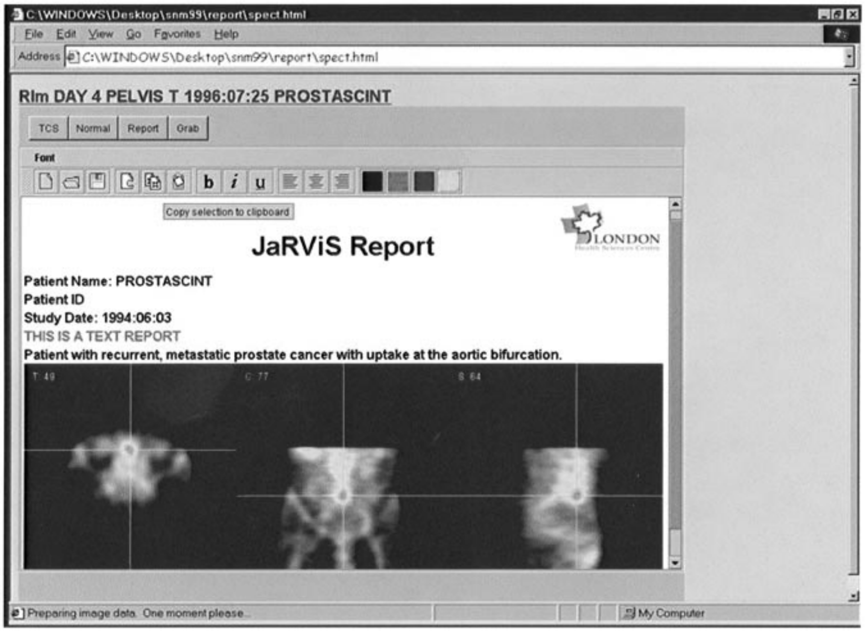

FIGURE 6. JaRRViS report, displayed within Web browser window. This portable file could be displayed on any computer with Web-browser software.

the interpretation will be easier, even if complicating factors such as large patients or unusually positioned hearts are present. The technologist should always note scan quality and should not hesitate to bring any unusual factors to the attention of the physician who will be interpreting the study.

The technologist should understand the physician's thought process in interpreting the study, and the factors that weigh into it, as well as the importance of timely, accurate, and medically relevant reporting. For example, the technologist can determine whether the patient has undergone a prior nuclear study, anticipate that the reader will need to compare it with the current study, and make sure it is available.

It is most often the technologist who is responsible for handling electronic image transfer. Technologists will need to become versed in at least the basic aspects of using networking software and maintaining network efficiency and data security. Troubleshooting will have to be done on additional computers, beyond the nuclear medicine acquisition device, since most departments will not have an on-site physicist or a networking professional who can be consulted at a moment's notice. With the introduction of Internet-based tools, users must be versed in the additional issues of security, confidentiality, and data integrity as well as new processing and reporting tools. Some of this new responsibility will likely fall on the technologist.

CONCLUSION

All of the new tools discussed here have become possible in the last few years only because of concurrent developments in different parts of the computer field. On the hardware side, these developments include networking hardware, increased availability of fast Internet connections to a broad range of users, more powerful desktop computers, and computer monitors capable of displaying high-information-density images with fidelity. In software, the growth of networking standards, the rise of platform-independent programming and display tools such as Java and HTML, and the advancement of standards-compliant Web browsers have all been important precursors to newer nuclear medicine–specific developments. The increasing availability of large medical databases, in synergy with the efforts of ICANL, the American Society of Nuclear Cardiology, and the Society of Nuclear Medicine to standardize the performing and reporting of myocardial perfusion SPECT, promises to help nuclear cardiology evolve into a more clinically useful and dependable modality, while integrating it into the overall patient care picture.

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REFERENCES

1. Zaret BL. House staff teaching and nuclear cardiology [editor's page]. *J Nucl Cardiol.* 1999;6:251.
2. Sorrell VL, Reeves WC. Who is interpreting nuclear cardiology studies in the United States, and what are the requirements for privileges? A national survey of institutional policies from 80 major medical centers. *J Nucl Cardiol.* 1997;4:309–315.
3. Bateman TM. Nuclear cardiology in private practice. *J Nucl Cardiol.* 1997;4(suppl 2, pt 2):S184–S188.
4. Ashare AB, Chakraborty DP. Artificial neural networks: better than the real thing? *J Nucl Med.* 1994;35:2048–2049.
5. Bateman TM, O'Keefe JH, Williams ME. Design and implementation of a

nuclear cardiology testing facility in a private-practice cardiology office setting. *J Nucl Cardiol.* 1997;4:156–163.
6. Simons M, Parker JA, Donohoe KJ, Udelson JE, Gervino EV. The impact of clinical data on interpretation of thallium scintigrams. *J Nucl Cardiol.* 1994;1:365–371.
7. Candell-Riera J, Santana-Boado C, Bermejo B, et al. Interhospital observer agreement in interpretation of exercise myocardial Tc-99m tetrofosmin SPECT studies. *J Nucl Cardiol.* 2001;8:49–57.
8. Krawczynska EG, Alazraki NP, Clark WS, et al. Effect of physician training on performance of interpreting cardiac Tl-201 SPECT studies: comparison to expert system results [abstract]. *J Nucl Med.* 1996;37(suppl):179P.
9. Bateman TM, Cullom J, Case JA. Wide area networking in nuclear cardiology. *J Nucl Cardiol.* 1999;6:211–218.
10. Wu LC, Yu CL, Wang JK, et al. Web-based information management in a PET center [abstract]. *J Nucl Med.* 2000;41(suppl):191P.
11. Lee SC, Wu LC, Liu RS. Dicom-based web PACS system [abstract]. *J Nucl Med.* 1999;40(suppl):323P.
12. Strauss LG, Kontaxakis G, Dimitrakopoulou-Strauss A. Implementation and performance of iterative PET image reconstruction methods for PC systems and a web based interface [abstract]. *J Nucl Med.* 2000;41(suppl):191P.
13. Holst H, Mare K, Nilsson T, et al. The evaluation of an automated method for the interpretation of lung scans [abstract]. *J Nucl Med.* 2000;41(suppl):13P.
14. Porenta G, Dorffner G, Kundrat S, Petta P, Duit-Schedlmayer J, Sochor H. Automated interpretation of planar thallium-201-dipyridamole stress-redistribution scintigrams using artificial neural networks. *J Nucl Med.* 1994;35:2041–2047.
15. Golish SR, Hove J, Schelbert HR, Phelps ME, Gambhir SS. Feedforward artificial neural networks for real time estimation of parametric images of myocardial perfusion using 13-N-ammonia positron emission tomography [abstract]. *J Nucl Med.* 1998;39(suppl):168P.
16. Lindahl D, Palmer J, Ohlsson M, Peterson C, Lundin A, Edenbrandt L. Automated interpretation of myocardial SPECT perfusion images using artificial neural networks. *J Nucl Med.* 1997;38:1870–1875.
17. Tagil K, Andersson L-G, Balogh I, et al. Evaluation of a new internet based system for interpretation of myocardial perfusion images. Presented at: 5th International Conference of Nuclear Cardiology; May 4, 2001; Vienna, Austria.
18. Garcia EV, Cooke CD, Folks RD, et al. Diagnostic performance of an expert system for the interpretation of myocardial perfusion SPECT studies. *J Nucl Med.* 2001;42:1185–1191.
19. Haddad M, Porenta G. A case-based reasoning system for an automated interpretation of myocardial perfusion scintigraphy [abstract]. *J Nucl Med.* 1996;37(suppl):178P–179P.
20. Cooke CD, Ordonez C, Garcia EV, et al. Data mining of large myocardial perfusion SPECT (MPS) databases to improve diagnostic decision making [abstract]. *J Nucl Med.* 1999;40(suppl):293P.
21. Wackers FJ. Intersocietal Commission for the Accreditation of Nuclear Medicine Laboratories (ICANL) position statement on standardization and optimization of nuclear cardiology reports. *J Nucl Cardiol.* 2000;7:397–400.
22. Bateman TM, Stowers SA, Herndon WM Jr. Statement on mobile and remote-site provision of nuclear cardiology imaging services. *J Nucl Cardiol.* 1997;4:174–177.
23. Cerqueira MD. The user-friendly nuclear cardiology report: what needs to be considered and what is included. *J Nucl Cardiol.* 1996;4:350–355.
24. Gainey WE, Cullom SJ, Moutray KL, et al. Description and performance of a nuclear medicine relational database management system for mining patient follow-up [abstract]. *J Nucl Med.* 1999;40(suppl):293P.
25. Keister J. Integrated PACS/RIS system streamlines workflow for radiologists and technologists. *Radiol Today.* 2001;2:27–29.
26. Fig LM, Shapiro B, Steventon RS, Gross MD. Can a voice recognition dictation system for nuclear medicine reports be successfully used in an academic hospital setting? [abstract]. *J Nucl Med.* 1999;40(suppl):293P.
27. Line BR. Knowledgebase (KB) toolkit for generation of nuclear medicine reports [abstract]. *J Nucl Med.* 2001;42(suppl):190P.
28. Somer EJR, Badawi RD, Hearns JL, Liepins PJ. A DICOM compatible internet remote reporting package for nuclear medicine [abstract]. *Eur J Nucl Med.* 1997;24:942.
29. Slomka PJ, Elliott E, Driedger AA. Java-based PACS and reporting system for nuclear medicine. In: Blaine GJ, Siegel EL, eds. *Proceedings of Medical Imaging 2000: PACS Design and Evaluation—Engineering and Clinical Issues.* Bellingham, WA: SPIE; 2000. Vol 3,980.

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