Imaging informatics is a distinct subspecialty of radiology that endeavors to improve the efficiency, accuracy, and reliability of radiologic services within the medical enterprise. Although picture archiving and communication systems (PACS) are a major focus of imaging informatics, there are many other ways in which technology can improve the efficiency of individual radiologists and of the entire department. Understanding informatics principles is important because these principles affect major purchase decisions, not only for PACS but also for other supporting software and for modalities themselves. This review, which is the first of two parts, will focus on PACS and its parts and on supporting software for PACS.

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Informatics is the study of how information passes from person to person and from place to place and how information is processed. Imaging informatics (previously called radiology informatics) is sometimes thought of as the study of how images get from one place to another, but in reality imaging informatics has a much larger scope. Virtually every aspect of a radiologist’s workday involves some form of communication: calling a colleague for patient history, calling a technologist to apply a protocol or check an image, reviewing images with a clinician, teaching a trainee, producing a formal report, justifying an examination to a third-party payer. All of these events fall under the purview of imaging informatics, and all of them, along with image interpretation itself, can become more efficient, more effective, and more reliable with the proper tools. Image interpretation may be the core of our value as radiologists, but that is only one element in the practical process of being a radiologist.

Imaging informatics has become a distinct subspecialty of radiology, with its own fellowship training and a formal curriculum for residents and fellows (1). The subspecialty society that supports imaging informatics is the Society for Imaging Informatics in Medicine (SIIM, formerly the Society for Computer Applications in Radiology) (2). SIIM is a 2200-member society with an annual meeting attendance of approximately 3000 people. There are seven active fellowship programs across the country, all of which combine clinical subspecialty training with informatics training (3).

At many academic institutions, there are radiologist-informaticians, who dedicate time to the study of informatics. But it is not only these individuals who need to understand the basics of imaging informatics. All practicing radiologists, whether in an academic or a private setting, are affected by informatics principles. As technologies such as picture archiving and communication systems (PACS) and speech recognition become ubiquitous, radiologists must be prepared to evaluate the software offered by different vendors, and they must understand the relative merits of different technologies. Appreciating this trend, the American Board of Radiology may also incorporate informatics questions into its written examination. This serves to emphasize the importance of imaging informatics to all radiology trainees.

Although radiologists may be the major beneficiaries of imaging informatics, all personnel in the radiology department should be familiar with informatics. An example is the PACS administrator, whose job is (among other things) to ensure that images reach the radiologist from the modalities (4). Radiologic technologists, too, need to understand the communication tools and infrastructure that enable them to perform their jobs efficiently and effectively and to correct problems with image quality. Nurses need tools to provide them with complete patient histories and to allow them to efficiently document the results of their interventions. Schedulers and billing personnel recognize the benefit of coordination between the referring clinician and the interpreting radiologist on subjects such as the reason for an examination. The ramifications of informatics are felt throughout the radiology department.

This review will focus on several applications of informatics to the radiology environment. This article is not intended to be a comprehensive review of any of these topics but rather an introduction to the basic components and terminology of imaging informatics. The subjects were chosen because they have pertinence to all clinical subspecialties within radiology. This present review, part 1 of the series, will focus on PACS and its parts and on supporting software that is designed to improve the efficiency or functionality of PACS. Part 2, to be published later, will focus on the ways in which informatics can affect the radiology reading room and on recent technologies in imaging informatics.

**PACS and Its Parts**

A functioning PACS requires many components working in close communication. Vast amounts of data pass through any PACS (over 50 GB per day may be generated at larger institutions), and there is an almost constant demand for access to these data from radiologists and referring clinicians. Along with modalities, network, workstations, and storage media, one necessary component of any PACS is a team of information technology personnel to keep the PACS running smoothly. These individuals require an in-depth understanding of all the elements in the PACS and will troubleshoot most problems. There are, however, some PACS elements that the practicing radiologist must be familiar with to ensure quality control and to understand how PACS performance can be undermined: workstation monitors, computer networks, storage devices, and image distribution.
Workstation Monitors

With the transition from film to PACS, traditional film image alternators have been replaced with PACS workstations. Instead of backlit view boxes, images are viewed on computer monitors. When choosing equipment, radiologists must understand the relative merits of different monitor technologies and hardware options.

CRTs and LCDs.—The first computer monitors were based on the cathode-ray tube (CRT) technology that had been used in televisions for decades. The long history of the CRT has allowed the basic technology to be optimized and the production costs to be minimized. A newer technology, the liquid crystal display (LCD), promises superior performance in many respects. The major advantages of CRTs are viewing angle and initial cost, whereas LCDs are brighter, smaller, have a longer life, and allow easier quality assurance.

A CRT will cost one-half to one-third as much as a comparable LCD. CRTs can be viewed from a wide angle (Fig 1), allowing several users to optimally view the image at the same time. This has obvious implications in a radiology teaching environment, where attending physicians and residents need to use the same monitor to discuss findings.

The required brightness (luminance) for medical displays is much greater than that for home and commercial uses. Medical LCDs are generally somewhat brighter than medical CRTs. Unfortunately, the luminosity of a CRT degrades relatively quickly. Thus, CRTs need to be replaced more often than do LCDs, and CRTs require more diligent quality assurance. The issue of brightness is important because radiologists may be able to interpret images more accurately on brighter monitors (5).

LCDs are a type of flat-panel monitor, so the amount of desk space required is substantially less than that for CRTs (Fig 1). This permits greater flexibility when designing a workplace environment.

Quality control for CRTs is more complex than that for LCDs. In addition to the degradation of CRT brightness, the curved screen of most CRTs causes distortion of the image, and the aspect ratio (the ratio of height to width) can be varied. Thus, images may appear too tall or too wide if the CRT has deviated from its calibration settings (Fig 2). LCDs, on the other hand, have a fixed geometry, and their aspect ratio never changes. Some LCDs also have the capability to dynamically change their luminosity so that the perceived brightness is constant over the life of the monitor.

The initial cost advantage of CRTs is offset by their shorter life span. Because CRT monitors will need to be replaced more often, the total cost of ownership is higher than that of LCDs. As the cost of LCDs continues to decrease and technological advances improve LCD viewing angles, it is likely that LCDs will completely replace CRTs for medical imaging.

Resolution.—The resolution of a monitor indicates how much data can be displayed at one time. Each dot on the screen is called a pixel, and the pixel resolution of modern monitors is measured in millions of pixels (megapixels). Spatial resolution is a measure of how many pixel lines are present in each millimeter (or inch) of the display screen. The higher the resolution of the monitor, the greater the cost. Also, at very high resolutions the monitor may be slow to respond. Thus, it is worthwhile to determine the minimum acceptable resolution needed for the images being interpreted at each workstation.

Cross-sectional modalities such as CT, magnetic resonance (MR) imaging, and ultrasonography (US) acquire data at a fixed pixel resolution (for example, a CT image is usually 512 pixels tall and 512 pixels wide). If four to six such images are placed on the screen at a time, the monitor need only have 1–2 megapixels to completely accommodate the data.

Conventional radiographs present a different problem. The number of pixels in a conventional radiograph is greater than the number of pixels on most display monitors. Thus, if the entire image is placed on the screen, the image must be represented without all of its fine details (this is known as down sampling). However, a monitor resolution greater than 2–3 megapixels has not been shown to improve interpretation speed or accuracy for conventional radiographs (6). Results of recent work (7,8) suggest that the lower resolutions acceptable for cross-sectional images may be diagnostically sufficient for conventional radiographs, although interpretation may take longer on a low-resolution monitor. The loss of fine detail on the low-resolution monitors is accommodated by software that permits zooming and panning of the image.

Mammography is the most demanding modality for monitor resolution (9). The need to consistently identify microcalcifications slowed the transition of mammography to a digital modality. Monitors in the range of 5-megapixel resolution are likely adequate for mammographic interpretation, but this modality is not as well studied as conventional radiography.

Color versus gray scale.—It might seem that a color monitor would be strictly superior to a monitor that displays only shades of gray. However, the
ability to display color comes at the cost of blurriness and brightness (10). Each pixel in a color monitor consists of a red, a green, and a blue element displayed next to each other. At normal viewing distances, this cluster blurs into a single-colored pixel. But the elements cannot be strictly superimposed, so there is a loss of sharpness to the image that may be important for radiologic applications. Historically, color monitors were of insufficient brightness to meet the needs of medical imaging, so grayscale monitors became more prevalent when PACS was first introduced. Nowadays, gray-scale monitors are preferred because they are less expensive than color monitors with similar specifications.

For most radiology applications, gray-scale monitors are ideal because most modalities acquire data along a single spectrum of values. There are numerous exceptions, such as nuclear medicine (particularly fused positron emission tomography/CT), Doppler US, and perfusion imaging. For these applications, a color monitor is needed and should be available at every PACS workstation.

Number of monitors.—The discussion of monitor options leads to a natural question: How many monitors and of what type are needed at each PACS workstation? Note that color applications in radiology tend to require lower resolution, so a low-resolution color monitor can be combined with high-resolution grayscale monitors to cover all applications at a single workstation. The low-resolution color monitor can also be used to navigate the images, leaving more space on the grayscale monitors for images and removing distractions.

When PACS was first introduced, some vendors tried to imitate a film alternator by providing eight full-size grayscale monitors at each workstation. It was later shown that PACS can be used more efficiently with fewer monitors, because the radiologist’s attention can be more focused (11).

The ideal number of monitors at a PACS workstation is a matter of personal preference, but the industry is tending toward one low-resolution color monitor combined with two high-resolution grayscale monitors (11). The precise gray-scale resolution is dictated by the types of images most frequently interpreted at that workstation.

Quality assurance.—It is the responsibility of the interpreting radiologist to ensure that image quality is adequate for interpretation. In the PACS environment, this responsibility extends to ensuring that the monitors themselves are working correctly (12).

Subtle changes in brightness or contrast can change the diagnostic accuracy of a PACS workstation.

On a daily basis, the monitors should be inspected to ensure that subtle shades of gray can be distinguished (contrast ratio). This is usually accomplished by subjectively evaluating a standardized test pattern. The aspect ratio of CRTs should also be checked on a daily basis.

These daily tests can be performed by the radiologist, but monitors also require upkeep on a monthly or quarterly basis, preferably performed by a medical physicist or information technology professional. For example, gamma correction is a method with which contrast is maximized among the medium shades of gray (at the expense of the extreme whites and blacks). Not only does this make image interpretation easier in the range of grays most often encountered, it also helps to ensure that each monitor shows the same data at the same brightness levels. Gamma correction is of such importance that it is a part of the Digital Imaging and Communications in Medicine (DICOM) standard for image transmission.

The American College of Radiology has recommendations about brightness and calibration that represent a minimum standard for monitor quality as-

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**Figure 2**

*Figure 2:* Demonstration of aspect ratio. Transverse computed tomographic (CT) image obtained through the orbits shown with (a) incorrect and (b) correct aspect ratios. Elongated globes in a might be mistaken for staphylomas. Ensuring proper aspect ratio is an important component of display quality assurance.
urance. However, most modern medical-grade monitors operate at levels that far exceed these recommendations. The American Association for Physicists in Medicine also has a task force that releases recommendations for assessment of display performance. Details are available at these organizations’ Web sites (13, 14).

It is worth reemphasizing that image quality is the responsibility of the interpreting radiologist. This includes ensuring that the PACS monitor is displaying the data appropriately.

**Networks**

A network of computers is the infrastructure that allows data to pass from the modalities to the PACS itself then to the radiologists’ workstations and to any additional long-term storage devices. The network allows the radiologists’ dictates to be distributed to clinicians and enables communication tools such as e-mail. Although any sizable radiology department will have information technology support personnel to maintain its computer network, a basic understanding of networks is helpful.

**Network elements.**—Most computers in a network can be classified as either servers or clients. A server is a computer that facilitates communication between and delivers information to other computers. A server does not usually have a person working at it; the server responds to requests from other computers on the network rather than to commands from a person.

Clients are computers that rely on servers to supply them with information. Radiologists will generally interact only with client computers, such as desktop personal computers. A workstation is a client computer that is dedicated to a particular use. In radiology, this implies a computer on which image interpretation is performed. (The terms server and client may also refer to software programs, with server software providing information at the request of client software.)

Networks also contain devices that route data from one computer to another. The most frequently encountered routing devices are switches, routers, and hubs. It is not necessary for radiologists to understand the differentiating features of these devices, but it is worthwhile to have seen the terms and to be familiar with their general function.

The other major elements in a network are storage devices, which maintain data that are not currently in use by any client and that provide that data on request. These devices are discussed in greater detail later in this review.

The topology of a computer network can be displayed diagrammatically, with each network element and its relationship to the other computers shown (Fig 3). The flow of data can then be plotted, and bottlenecks or points of failure can be identified.

**Figure 3:** Schematic of a computer network shows various network elements. This is an important troubleshooting tool with which bottlenecks and failure points can be identified.

Types of networks.—A local area network (LAN) is a network of computers in proximity to each other, usually within a single hospital (15). A wide area network is a collection of LANs connected together and spanning, for example, an entire health care system.

Most networks are referred to as “wired” because they rely on physical connections (copper or fiber optic wires) between computers. In contrast, wireless networks use radio waves to transmit data between computers. Because potentially sensitive information is being broadcast into the air, extensive security measures are needed for wireless communication.

One network model that is of particular interest to practicing radiologists is the virtual private network, or VPN. When data are transmitted within a LAN, privacy can be relatively ensured because all of the connecting cables are within the physical boundaries of the hospital. However, when data are transmitted across the Internet (eg, when a
radiologist wishes to review an emergent image from home by using teleradiology), there is a substantially greater security risk because the data are being sent across an unpredictable chain of unknown computers. The VPN is a technology that allows a computer outside the LAN (eg, a radiologist’s home computer) to connect to the LAN (eg, the hospital PACS) with a level of security similar to that of computers physically within the LAN. Such security measures are essential whenever patient-identifiable information is transmitted. 

Bandwidth.—Network bandwidth is the maximum rate at which data can pass between two points in the network. Bandwidth depends mostly on the transmission medium (copper wires, fiber optics, wireless) but also on the number of computers sharing the same infrastructure. The time required for an image to be sent from a PACS server to a workstation depends heavily on the bandwidth of the intervening network and on the number of simultaneous requests from users.

When too many computers are placed on the same network, performance may decline to unacceptable levels (eg, “the PACS is too slow”). Although the bandwidth of a hospital network can be increased to accommodate more computers, this is usually prohibitively expensive. During network planning, it is important to recognize that mission-critical systems such as the PACS should be granted dedicated bandwidth that is used only by PACS workstations and servers. This prevents nonessential data transmissions from interfering with departmental productivity.

Image compression is a means of decreasing the bandwidth needed to transmit images rapidly. By using the inherent redundancies that are present in any image, the amount of data needed to define the image can be minimized. If every detail of the original image can be faithfully restored, the compression scheme is called lossless. Otherwise, the compression scheme is called lossy. There is considerable debate regarding the degree of lossy compression that is acceptable in radiology without decreasing diagnostic accuracy (16–18). Many PACS vendors avoid this issue by using only lossless compression. 

Security.—Network security is a topic that receives vast amounts of attention in finance and industry because of the threat posed by data loss, theft, or corruption. Despite the passage of the security regulations in the Health Insurance Portability and Accountability Act, or HIPAA, network security remains one of the weakest aspects of many hospital infrastructures (19). There are several reasons for this. Traditional medical culture is slowly changing to place a greater emphasis on privacy and security. Compared with other industries, hospitals also have poor physical security. That is, people who are not employees are allowed relatively free passage into the hospital. Although information technology professionals observe most of the security operations for hospital networks, it is important for radiologists (and all physicians) to be aware of the most frequent security errors that can lead to compromise of patient data. Computer users will often make the assumption that security precautions are less important on personal computers than on dedicated workstations and may remove or disable security features that they see as annoying. In fact, personal computers within the hospital network are particularly vulnerable because of their varied uses, so security should be emphasized (20). As network security receives greater attention, both in the media and from hospital administration, informatics solutions are being deployed more extensively within the medical environment. Removal of patient-specific information (“anonymization”), encryption of patient information, and biometric identification of users are examples of technologies that may be employed to preserve patient confidentiality.

Storage
Modern radiology departments generate a tremendous amount of image data. In the film era, this information was stored in warehouselike film libraries and often required hours to days for retrieval of old studies. In the PACS environment, rapid retrieval is expected for all relevant comparison studies. Whether this retrieval time is measured in seconds, minutes, or hours depends on the type of digital archive that supports the PACS (21).

Advantages of different media.—There are several options for long-term storage of digital data: spinning disks (eg, hard drive on a personal computer), magnetic tape (eg, audio cassettes), optical media (eg, compact discs and digital video discs), and solid-state (eg, USB [universal serial bus] flash memory cards) (22). Most PACS use some combination of these. Optical media require more support personnel than do other options, and they do not scale well (ie, they become more difficult to use as the volume of data increases), so they are decreasing in popularity. Solid-state media are as yet too expensive for large-scale storage but may become preferred as the technology improves.

Most PACS use either magnetic tape or spinning disks for long-term storage. The major advantage of magnetic tape is cost. The major disadvantage is retrieval time. Just as an audio cassette tape cannot instantaneously access any song, tape drives must rewind through the spool to arrive at the appropriate image. This delay can be exacerbated if the correct tape must be manually loaded onto the reader.

Spinning disks are more expensive than magnetic tape or optical media; however, they have a marked advantage in terms of retrieval time. Just like data on the hard drive of a personal computer, the data stored on spinning disks are always immediately available. The only delay derives from the time needed to send the data from the archive to the PACS. As the cost of spinning-disk technology continues to decrease, this medium is becoming the preferred (or sole) method for storing image data in many PACS.

Online versus off line.—Some of the data on a PACS are immediately available whenever a radiologist requests them. This arrangement is called online...
storage, and it usually includes the most recent images and their relevant comparison studies. Off-line storage refers to images that have been placed in a less accessible archive and need to be restored to online status before they can be viewed.

In a single-tier storage system, all the data are online all the time and are stored on a single medium (usually spinning disks). In a multtier storage system, some of the data are online (usually on spinning disks), while other data are off line (usually on optical media or tape).

Clearly, a single-tier system, in which all data are online, would provide superior performance for radiologists and clinicians, but it is sometimes prohibitively expensive. So, the images most likely to be viewed are placed in online storage, and unused images are relegated to off-line storage. When an off-line study is unexpectedly needed, there can be a delay of minutes to hours while the data are moved online. Near-line is an imprecise term suggesting that off-line data are readily, although not immediately, available.

Amount of storage.—Determining storage requirements is one of the most difficult aspects of planning a PACS. The decision is made more difficult by the unpredictable surges in data volume when advanced technology (eg, 64-detector CT) is introduced. The proper ratio of online to off-line storage, as well as the proper storage media, must be chosen to optimize cost and system performance. There are two important principles in determining storage requirements: (a) Storage is easy to underestimate—the PACS will probably need more storage than planners suspect—and (b) the system must easily accommodate additional storage at a reasonable cost in the future.

Redundancy.—Because medical imaging data are of critical importance, it is unacceptable to permit one computer error to destroy all copies of the data. In the film era, it was prohibitively expensive to make copies of every radiograph; however, in a digital environment, the benefit of securing the data outweighs the incremental cost. The term redundancy refers to storage of multiple copies of imaging data. (Redundancy is also used when several computers or network components perform the same job—if one element fails, the redundant elements keep the system functioning until the failed component can be replaced.)

A redundant array of inexpensive disks (RAID) is the most frequently used redundancy system in PACS storage. In a RAID, the data are spread over several hard drives, such that if any one drive fails, the data can be reconstructed from the surviving drives.

Another form of redundancy is the long-term archive. Even as studies are sent to the PACS from the modality, they are also copied to the long-term archive that will store them when they are no longer in online status. PACS with a single-tier architecture must have another backup system for archiving in case the main storage fails. (This backup system usually makes use of inexpensive storage media, because performance is not an issue.)

A third form of redundancy is related to disaster recovery. Disaster recovery asks the question, “What if the entire city is destroyed?” Additional copies of data are stored at a geographically distant site as an extreme emergency backup.

Although the term redundancy is often used in the setting of data storage, virtually every component of a PACS requires a “failover,” or backup, mechanism in case of failure. This decreases the likelihood of a total system failure in the inevitable circumstance of the failure of a single component.

In summary, the cost of storage media is continually decreasing, but the amount of data generated by radiology departments is continually increasing. It is as yet unclear which trend will dominate. It may be that the cost of storage media will decrease to levels at which single-tier, all-online, immediate-access storage systems become universally affordable on every PACS.

Image Distribution

One of the major benefits of PACS over film is the efficient distribution of images. Multiple users can view the same study at the same time, and images can be sent to any location almost instantaneously. The devil, however, is in the details. It is surprisingly difficult to send the appropriate images to the appropriate place at the appropriate time. It is also difficult to construct a computer interface that allows users to sift through the myriad patients in the enterprise to find the one pertinent individual.

Commercial PACS do a good job of presenting a list of patients to a radiologist. Pertinent patients are easy to identify because there is no dictated report accompanying the images. Clinicians, however, are less interested in the status of the dictation and more interested in which patient they are caring for at that moment. Thus, the clinician’s work list must be designed differently from the radiologist’s work list. An outpatient clinic might have still different requirements—the pertinent patients are the ones scheduled for that day, regardless of which doctor is involved.

Distribution of images outside of the hospital presents additional hurdles. Radiologists who wish to review studies from home (eg, when they are on call) require a different distribution model. The bandwidth available for transmitting images to a home personal computer is likely to be far less than the bandwidth available at a hospital, so care is needed to keep from overloading the extended network. Remote physician offices have similar issues of bandwidth, as well as additional security issues. Care must be taken to prevent inadvertent exposure of confidential patient information. The term enterprise distribution refers to the delivery of images anywhere outside the confines of the radiology department.

Supporting Software

PACS is the best-recognized application of informatics in radiology, but PACS alone cannot address the needs of the practicing radiologist. A bevy of additional software products are used alongside with or are integrated into the PACS to further improve the radiologist’s efficiency and effectiveness.
Speech Recognition

Radiologists have always been under pressure to provide referring clinicians with finalized reports in a timely fashion so that patient care can be rapidly adapted to the radiologic findings. The definition of timely, however, has changed over the past 2 decades from a few days to hours or minutes.

Turnaround time measures the interval between the completion of a study and that study’s report becoming available to the treating physician. The advent of PACS and digital dictation systems have decreased turnaround times dramatically, but there is still considerable latency in the transcription process. The goal of speech recognition is to substitute a computer for the traditional medical transcriptionist to speed up transcription.

In addition to improved turnaround time, speech recognition boasts decreased transcription costs. Unfortunately, this financial incentive has been the driving force for the early adoption of speech recognition, in some cases before the technology was mature. Thus, users of speech recognition were faced with poor recognition accuracy, such that the radiologist was forced to act as his or her own transcriptionist, correcting the many mistakes of the speech-recognition program. In some instances, radiologists were forced to modify their dictation style, slowing down to accommodate the speech-recognition engine. These inefficiencies have resulted in poor radiologist acceptance of speech-recognition technology.

Modern speech-recognition systems have addressed many of the problems that plagued their predecessors. Advances in recognition engines allow radiologists to dictate in a natural cadence. Radiology-specific language models ensure that words used commonly in radiology reports, but rarely in spoken English, are still considered favorably. Background recognition prevents the radiologist from being distracted as words appear on the computer screen. Combined systems that incorporate both speech recognition and human transcriptionists can balance the advantages of improved turnaround time and high accuracy. But perhaps the most important advance in speech recognition is the integration of speech-recognition systems into PACS. If speech recognition and PACS act as a single software system, radiologists can maximize their efficiency (Fig 4).

In the setting of speech recognition, the term macro refers to predefined text that may be used instead of or in addition to free-form dictation (23). Macros improve the efficiency of some speech-recognition systems, particularly when the accuracy of the speech-recognition engine is poor. However, the long-term effect of macro dictation on radiology training and report quality remains uncertain (24).

The term voice recognition is frequently used as a synonym for speech recognition.
recognition. Strictly speaking, voice recognition refers to the task of identifying an individual on the basis of the sound of his or her voice, usually for security purposes.

Digital Teaching Files
Although most academic radiology departments have completed the transition to PACS, few have developed an adequate substitute for the traditional radiology teaching file (25). Many academic institutions have developed in-house digital teaching files; several Web-based solutions exist, and standardized formats have been developed for sharing cases between institutions. However, robust digital teaching files have not yet become commonplace in academic centers.

Conventional radiology teaching files fail in the PACS environment for several reasons. First, the Health Insurance Portability and Accountability Act has rendered most film-based teaching files noncompliant owing to the lack of anonymization. Also, traditional teaching files do not have the portability that trainees have come to expect in a digital environment; the cases should be available on virtually any computer at the medical center or the medical school. Revisions to accommodate more advanced teaching or techniques are difficult with film and paper but easy with a digital teaching file.

The Medical Imaging Resource Center (MIRC), sponsored by the Radiological Society of North America, is a means of sharing radiology cases (and other information) between institutions (26). MIRC supplies a database scheme that any institution can use to organize its teaching files. The institution may then choose to have their teaching file listed on the MIRC Web site (http://mirc.rsna.org) so that teaching files can be searched in a predictable manner across multiple institutions (Fig 5).

Incorporating digital teaching files into the PACS is a critical step in making the creation process reliable and efficient. If a separate piece of software is necessary to save an interesting case, many cases will be lost because the radiologists are too busy at the time of interpretation. Despite this, most PACS vendors have not incorporated digital teaching files directly into their PACS (27).

Image Processing
Image processing has become an essential part of every radiology practice. From simple applications, such as multiplanar reformating, to advanced techniques, such as diffusion-tensor imaging and virtual endoscopy, manipulation of images is now commonplace. The applications listed below represent a small subset of the burgeoning field of image processing. Computer-aided detection.—Computer-aided interpretation is a general term for software that analyzes a medical image to assist a radiologist’s interpretation. Computer-aided detection is a type of computer-aided interpretation system in which a computer program suggests regions of interest that the radiologist might have overlooked (28). Computer-aided detection has found greatest application in the field of mammography, where assessment of...
suspicious areas is improved when radiologists incorporate computer-aided detection (Fig 6) (29). Computer-aided detection for lung nodules is being validated, both for conventional radiographs and for CT images (30). Additional applications of computer-aided detection, such as for colonic polyps and pulmonary emboli, are under development.

It is important to note that most computer-aided detection systems are designed to achieve high sensitivity (with many false-positive results) while relying on the radiologist to supply specificity. Thus, radiologists must approach images analyzed with computer-aided detection with healthy skepticism, or the numerous false-positive results may decrease the accuracy of the examination.

As with much of the supporting software discussed in this section, integration with PACS remains a substantial hurdle in the full implementation of computer-aided detection (28). Inefficient computer-aided detection implementations can be a major barrier to radiologist acceptance. Also, the medical-legal ramifications of computer-aided detection are uncertain (31).

Dual-energy subtraction.—Dual-energy subtraction thoracic radiography is in clinical use at many institutions (32). The patient is irradiated twice, with different photon energies, and the results are compared to determine the relative density of different anatomic structures. The images are displayed in a format that emphasizes either bone or soft-tissue structures (Fig 7). The major disadvantage of dual-energy subtraction radiography is an increase in radiation dose.

Three-dimensional visualization.—One of the traditional disadvantages of CT, as compared with MR imaging, has been the inability of CT to acquire images in arbitrary planes. Modern CT scanners, however, have the capacity to create volumetric image sets that can be used to create high-quality images in any plane of reference or to allow advanced three-dimensional visualization techniques such as visceral fly-through and volume rendering. Because radiologists are most familiar with the transverse plane of imaging, scanners still provide transverse images as the default presentation mode. It is unclear, however, whether this traditional way of interpreting studies is the most effective or most efficient. Innovative human-computer interfaces, as well as advanced models for image interpretation, have the potential to completely transform the way that radiology is practiced (33). Such initiatives are still in the early stages of development.

Asynchronous Communication Tools

Synchronous communication occurs when both parties are simultaneously in contact. Asynchronous communication occurs when one party creates a message that is received at a later time. The distinction between these modes of communication is exemplified by the difference between a telephone call (synchronous) and an e-mail message (asynchronous). Asynchronous communication models are slowly replacing the more traditional synchronous communication models in radiology departments (34).

Electronic preliminary reports allow radiologists (and especially trainees) to distribute their interpretations throughout the hospital system at the time they first evaluate the images (Fig 8). This discourages repeat consultations and permits clinicians to review results when it is most efficient to their own workflow. A secondary benefit of electronic preliminary report generators is the ability to catalogue and review misinterpreted cases.

Communication with referring physicians, a notoriously inefficient aspect of radiology practice, can be improved with automated paging tools that alert referring physicians to important findings in radiology reports. The importance of communication between radiologists and clinicians, particularly regarding communication of unexpected results, is receiving increased attention from the popular media and from regulatory agencies, leading to greater emphasis on informatics solutions.

Asynchronous communication tools can improve the efficiency of communication in the radiology department as well—for example, by incorporating nursing assessments or technologist

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**Figure 8**

Preliminary reports integrated with PACS. Short preliminary interpretations (eg, overnight resident interpretations) are placed in left text box and remain closely associated with the images in the PACS. Right text box is used by the final interpreting radiologist to communicate final results and adjudicate preliminary interpretations. A preliminary report generator integral to the PACS allows robust asynchronous communication of results, with the PACS infrastructure used for distribution. Data mining for discordance rates and quality assurance are also possible.
feedback into the PACS. Imaging protocols that would previously have required direct communication between radiologist and technologist can be handled through scheduling software. Tele-radiology consultations can also be made more efficient with appropriate communication tools.

The most important advantage of the asynchronous model is a reduction in disruptive events. Answering a phone call, for example, is one of the most disruptive events in a radiologist’s workflow. Thus, from an informatics perspective, fewer phone calls is an indicator of a more efficient system. Note that both participants benefit from an asynchronous model: They both use the time flexibility to better incorporate the communication event into their schedules.

Asynchronous communication is not without drawbacks, however. The reduced face-to-face contact between radiologists and clinicians can result in fewer requests for consultation and less robust clinical histories. Also, emergent findings must be communicated synchronously to ensure that the message is received in a timely fashion.

**Summary**

PACS has become an essential element in many radiology practices. To use PACS most effectively, radiologists must understand the technology underlying the digital environment. It is also helpful for radiologists to have additional software that expands the functionality and efficiency of PACS.

**Glossary**

Listed below are commonly encountered imaging informatics acronyms and terms.

**CAD** (computer-aided detection; also, computer-aided diagnosis) and **CAI** (computer-aided interpretation)

Image-processing techniques in which software highlights portions of an image to direct the radiologist’s attention to potential abnormalities or assists in construction of a differential diagnosis

**CRT** (cathode-ray tube)

Display monitor technology that derives from television (see also **LCD**, liquid crystal display)

**DICOM** (Digital Imaging and Communications in Medicine)

Communication standard for medical imaging devices developed by the American National Standards Institute

**DTF** (digital teaching file)

Electronic replacement for the teaching files used for resident self-instruction

**HIPAA** (Health Insurance Portability and Accountability Act)

Federal legislation that dictates how patient medical information may be used: Patient privacy and electronic security are the major elements applicable to radiology.

**IT** (information technology)

Generic term for applications of computers and other data systems: Computer support personnel are referred to as IT professionals.

**LCD** (liquid crystal display)

Monitor technology that allows for flat panel displays (see also **CRT**, cathode-ray tube)

**LAN** (local area network)

Group of closely connected computers, usually within a single building

**MIRC** (Medical Imaging Resource Center)

Radiological Society of North America initiative to facilitate sharing of radiologic data (especially teaching files) between institutions

**PACS** (picture archiving and communication system)

Computer network dedicated to the storage, retrieval, and display of medical images

**RAID** (redundant array of inexpensive disks)

Common means of achieving redundancy to protect against data loss when storing large amounts of data, as in a PACS

**SCAR** (Society for Computer Applications in Radiology)

Former name of the Society for Imaging Informatics in Medicine

**SIIM** (Society for Imaging Informatics in Medicine)

Subspecialty society devoted to imaging informatics, known as the Society for Computer Applications in Radiology until April 2006

**SR** (speech recognition)

Software that converts spoken words into electronic text; the electronic equivalent of a medical transcriptionist (SR is also used for structured reporting, which will be discussed in part 2 of this review)

**VPN** (virtual private network)

Security software that allows users outside of the hospital environment (eg, radiologists viewing images from home) to safely view private patient information

**WAN** (wide area network)

Loosely connected group of computers, usually encompassing an entire medical enterprise

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