CHAPTER

6

REENGINEERING WORKFLOW: THE RADIOLOGIST'S PERSPECTIVE

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Busy day in the department. Morning: read several kidney studies and consulted on a fx. Home for lunch: stopped at drug store. Cut grass. Afternoon: read 3 studies. Organized cases. Home at 4:00. Took Lucille to see Forbidden Planet.

May 1956 entry in the diary of Col. William LeRoy Thompson, MD
First Chair and Registrar of the Department of Radiologic Pathology
at the Armed Forces Institute of Pathology, Walter Reed Army
Medical Center

Ask almost any observer what has changed most about the practice of radiology in the last half century and the immediate answer will be the technology. New modalities, interventional techniques, and the digitalization of almost every aspect of image acquisition, retrieval, processing, reporting, and archiving have profoundly altered the look of the imaging department. Ask a radiologist the same question, however, and he or she will respond that the most fundamental and challenging change in actual practice has been in the pace of work demanded of the individual who interprets the images. Gone are the days of a few studies in the morning, home for lunch, and a few more in the afternoon, as Colonel Thompson outlined in his diary at Walter Reed in 1956. Almost gone are the days of single- or two-view studies, interpreted on film and returned with dictated and manually transcribed reports to the referring physician.

Instead, an extraordinarily rapid and exponential growth in the number of images that constitute a single study, as well as the performance of numerous studies per patient, has multiplied the daily total of images presented to many radiologists by factors of not tens or hundreds but thousands. Tenacity and creativity have joined sensitivity and specificity as necessary metrics of radiologic success, as once-daunting 8-channel computed tomography (CT) datasets are replaced by those generated from 64-channel studies, and modalities from magnetic resonance (MR) to ultrasound (US) to fusion techniques in nuclear imaging yield increasingly large and complex groups of images. As Horii and others have pointed out, the size of these datasets has actually accomplished what logic and documented successes sometimes failed to do. These images form the "first group of examinations that cannot practically be printed to film for interpretation." A 1000-image CT examination—now commonplace in many institutions—would require a minimum of 67 film sheets to print (using a 4×4 matrix on film) and would take up 17 panels of a 4-light-box mechanical film changer for each window/level combination. The image explosion has made the transition to filmless imaging mandatory for many who once considered it an interesting future option.

The result over the past 5 years has been an increasing focus on workflow issues relating to the essence of radiologic practice: the process that occurs at the interface between the interpreter and the image. The literature documenting radiologist workflow issues is growing. Of course, the tasks of the radiologist at the workstations are part of a larger workflow and depend on a number of factors, including effective picture archiving and communication systems (PACS) integration with the radiology and hospital information systems (RIS and HIS, respectively), worklist management, workstation design, and innovations in the interpretation process, reporting, and interactions with clinicians and the larger medical enterprise. Less studied but equally important are the effects of room design and ergonomics on radiologist workflow and productivity as well as the need for reliable metrics and tools by which such productivity can be assessed and compared.

Because PACS serve increasingly as the nexus and conduit for the work of the radiologist, a number of other chapters in this book cover in greater detail the technical elements that make up routine workflow. Our goal in this chapter is to provide background, overview, and resources on current challenges and benefits associated with various elements of radiologist workflow.

BACKGROUND

For a number of reasons, including the fact that radiologists are the most expensive members of the imaging department's staff, interpretation workflow has been studied for many years to determine which factors influence productivity and accuracy. These studies took on additional importance when quantifiable results were needed to bolster the transition from film-based to filmless imaging in many institutions. Studies performed at the Baltimore Veterans Affairs Medical Center (BVAMC) documented an increase in radiologist productivity by more than 50% over the course of such a transition. This marked improvement occurred despite the fact that radiologist reading times decreased only slightly, by approximately 8% to 15%. The improvement was believed to be the result of a combination of complex factors, including more effective sharing of the workload by the radiologists, fewer interruptions, immediate availability of old examinations and reports for comparison, and the elimination of the film library and the inefficiencies and time delays associated with it (see Chapter 5 for information on departmental workflow effects that contributed to overall increases in productivity). Since the time of our original report, many other groups of radiologists have reported similar increases in productivity during the transition to filmless operation with an enterprise-wide PACS. Although this transition has been made in a variety of settings, from academic to private practice and in countries with varying reimbursement, personnel, and patient characteristics, some elements of success—as well as continuing challenges—remain constant.

PREPARING FOR INTERPRETATION: WORKLISTS, ARCHIVE ACCESS, AND INITIAL DISPLAY

Among the most important determinants of radiologist and clinician performance is the time required for a PACS workstation to retrieve one or more imaging studies, to display them for interpretation, and to present a suitable choice of workstation tools that allow the radiologist to glean as much clinically significant information as possible about the images. Studies that we have performed at the BVAMC and the University of Maryland have suggested that the first image from an 8-megabyte computed radiography study should take less than 3 seconds to display. Cross-sectional images, such as 512 × 512-pixel CT images, should display at a rate of at least 5 per second or faster. Our data suggest that image display performance that is significantly slower may result in a significant decrease in radiologist reading speed and produce increased levels of fatigue.

Manufacturers of PACS originally took one of two general approaches to the delivery of images to a radiologist's workstation. In the first, images were stored on a single, large, short-term storage unit, typically a redundant array of inexpensive disks (RAID). With this approach, workstations communicated directly with this centrally located storage device over a very fast network for image retrieval. The major advantage of this approach was the flexibility to rapidly retrieve any images at any location for both radiologists and clinicians. The major disadvantage was that it required a fast network in which single points of failure posed threats to continuous operation. Such systems were vulnerable to a major loss of function in the event of failure of the short-term storage device.

The alternative PACS architecture for delivery of images utilized a model that more closely emulated (and had many of the disadvantages of) a film-based environment in which films were sent to or placed on a film alternator. With a PACS, this was accomplished electronically by routing appropriate images to one or more workstations that were most likely to be used to review those image studies. Images to be read and comparison studies were stored locally on the hard drives (local storage) of the workstations themselves. Images could be intelligently routed to any number of workstations most likely to retrieve these studies. For example, all CT examinations could be routed to one or more workstations dedicated to interpretation of CT examinations or to the workstations or radiologists likely to read those studies on any particular day. Relevant comparison CT, general radiographs, or other studies deemed to be likely to be needed for comparison could also be routed to those workstations automatically, using predefined rules determined by the radiologists. The major advantage of such a system was independence from failure of any one component of the PACS or even the network itself. The disadvantage was the difficulty in selecting rules that would anticipate often unpredictable and spontaneous requirements of radiologists for comparison studies and older imaging studies that could be requested by clinicians for review. The other disadvantage of this architecture was the tendency for workstations to require a greater amount of local storage as well as the inefficiencies of storing images in multiple locations.

Fortunately, most PACS now combine the two approaches to minimize disadvantages and optimize benefits. (The currently available choices of PACS architectures are discussed in detail in Chapter 13.) For example, PACS that use a central hard drive (or RAID) may also employ mirrored or backup systems to further decrease the likelihood of a general system failure. Those systems that use local workstation storage now create more central "nodes" or short-term image servers that store images for a cluster of workstations. This can result in more efficient storage and retrieval and decrease the need for very specific algorithms for routing images to a particular workstation. It is likely that this trend will continue in the future and will significantly blur the differences between the two approaches to short-term image storage and distribution.

The combination of the use of modality worklists, display default protocols, and a fast image retrieval and display system now provides the ability to customize the radiology workflow process. Given these workflow and performance features, radiologists should be substantially more productive with less fatigue than in the conventional, film-based environment.

WORKLISTS AND WORKFLOW

Other chapters in this book address questions of workstation accessibility, security, and sign-on. Identifying the appropriate images to be read and connecting these images with the appropriate patient data and relevant priors, however, have always constituted the first major step in the radiologist workflow process. This step has changed profoundly within the last decade.

To maximize the efficiency of the workflow of diagnostic radiologists, early PACS adopters discovered that it was important to achieve paperless as well as filmless operation. Even today, the efficiency of many PACS implementations is hampered by the failure to eliminate paper from the radiologists' (and others') workflow process. In paper-based departments, radiologists began their work when presented with a stack of forms that contained information about the patient, examination, and reason for the study, with limited additional information, such as the name of the ordering physician or service, patient location, and so on. The radiologist then would use the information on these forms to enter patient or study identification manually or use a barcode reader or other mechanical tool to identify the patient and study to the workstation.

In the filmless department, these steps (and the attendant high rate of introduced error) have been eliminated by the implementation of worklists that define the type of unread studies to be presented for interpretation and their order of presentation. Worklists are shared, enterprise-wide rosters of unread studies, which, through the PACS, are integrated with a wealth of additional information. The worklist acts as a database filter that allows a radiologist to view images defined by anatomic regions (e.g., chest, neuroradiology, or musculoskeletal) or modality (e.g., ultrasonography, nuclear medicine, angiography, or special procedures) or any combination of these. The advantages of worklists for radiologists include the ability to sign in at any location and have full access to all unread examinations in their area or areas of expertise at any time, the ability for multiple radiologists to share responsibility for reading similar types of studies, and the performance improvements associated with the elimination of manually keyed or barcoded patient or study information.

The physical time savings for all radiology personnel and especially for the radiologist are evident. However, smooth implementation of shared worklists across the enterprise were hindered for a number of years by problems with interfaces between and among the RIS, HIS, PACS, and other hospital or practice information systems. The development and acceptance of the Digital Imaging and Communications in Medicine (DICOM) worklist standards, which offer guidelines for electronic communication between the imaging department and other parts of the hospital enterprise, provided the missing link that many institutions needed to begin to successfully implement worklists at the radiology workstation. The Integrating Healthcare Enterprise (IHE) initiative of the Radiological Society of North America and the Healthcare Information and Management Systems Society has addressed many of the remaining challenges associated with the lack of plug-and-play compatibility that resulted from the substantial flexibility (or looseness) of the Health Level Seven (HL7) and DICOM standards and those of other information technology systems.

Implementation of DICOM modality worklist management software has been reported to reduce input errors from 6.4% to 0.1%. In another study, a pre-PACS CT transmission failure rate of 7.6% (largely the result of human error in data entry) was reduced to 3.5% after the addition of DICOM worklists, with a much smaller portion of that percentage accounted for by human error (Figure 6.1).

Worklists can also be generated using an algorithm designed to prevent studies from being read and reported more than once (overreading), thus increasing overall radiologist productivity and reducing the possibility of conflicting recommendations. They can also be customized so that images can be used in resident or teaching review.

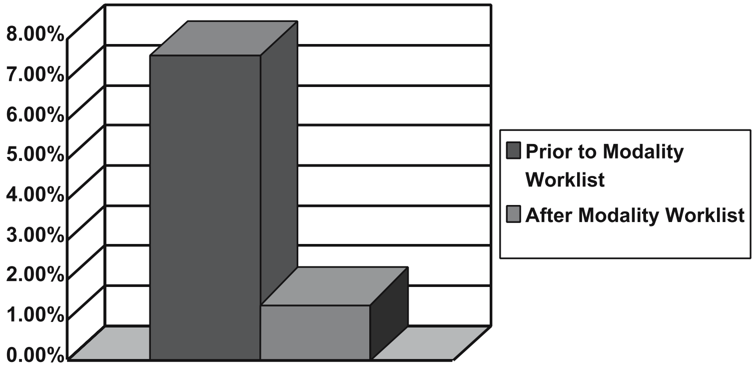

FIGURE 6.1

The CT transmission error rate was cut dramatically after the introduction of modality worklists.

PRE-FETCH

One of the workflow rate-limiting steps in the process of image retrieval and display is related to the fact that retrieval of images from long-term storage from an optical, magneto-optical, or tape archive is quite slow. In fact, retrieval times can be 10 to 100 times slower from long-term than from short-term storage, depending on the PACS architecture and equipment. Archiving and retrieval are addressed in other chapters of this volume.

Despite the more widespread use of RAID for both short- and long-term storage associated with substantial cost reductions in "spinning disk" archives, strategies to minimize the likelihood of a delay in image retrieval remain important elements in well-planned workflow. Such strategies use a set of algorithms (rules) that attempt to maximize the likelihood that the required images are available in short-term storage. The goal is to have the optimal number of relevant priors available without initiating unnecessary transfers from long-term storage. This process is an excellent example of the advantage of a PACS-HIS-RIS that forms an "intelligent" system, and numerous algorithms have been suggested and investigated.

One of the most straightforward examples of image pre-fetch is storage of new and historic examinations locally at a workstation. With this PACS architecture, images and predefined prior studies (for example, the last two studies that match both modality and anatomic location) are routed to a particular workstation or workstations. This pre-fetch strategy can also be used in a system in which workstations share a single RAID server. In this type of system, predefined relevant priors are retrieved from long-term storage automatically when a new imaging study is performed.

Other pre-fetch strategies can substantially increase the possibility that images that are likely to be needed by the radiologist or clinician are available on a local workstation or server. For example, image pre-fetches can be triggered based on a scheduled or new admission to the hospital, a scheduled outpatient appointment, or a transfer of a patient from one location to another within the hospital. Our analysis of the RIS database at the BVAMC indicated that a relatively small number of studies can be pulled to achieve a high likelihood that the required studies will be available on local storage. We found that if a PACS retrieved the most recent 30% of a patient's previous examinations into a short-term storage area before an outpatient appointment, there was a 91% probability that the required images would be available on the server rather than in the long-term archive. Such a pre-fetch strategy is the digital and much less labor-intensive equivalent of pulling film jackets in advance of outpatient visits and can be very effective in optimizing radiologist and clinician workflow in the review of imaging studies.

HANGING PROTOCOLS/DISPLAY

One of the more complex processes in reading conventional film was the arrangement of images from current and previous studies on a view box or film alternator. In a film-based department, radiologists typically functioned in one of two ways. In the first, the radiologist was responsible for taking a new study and finding comparison studies from a film jacket. Often, the film librarian placed these outside the film jacket. The radiologist then took these examinations and arranged them on a series of view boxes. The radiologist then found any relevant old reports, interpreted the study, took the films back down, and (with luck) placed them back into the correct film jacket. In the second mode, the study to be read was placed on a film alternator with any relevant films and reports. The competent film librarian learned how each radiologist preferred to have his or her films arranged for specific studies. Having the fileroom personnel arrange the films resulted in improved workflow for the radiologists but required additional time and fileroom staff. The hanging and removal of the studies also created delays in radiologist workflow, because the radiologist often had to wait for studies to be hung, then taken down, and new studies to be put up. The general in-house criteria that determined how film would be placed on film alternators or view boxes were referred to as "hanging protocols" or "display protocols."

A PACS softcopy workstation automates many of these manual workflow steps, eliminating delays in the display of imaging studies. Hanging protocols can be executed much more rapidly and reliably and can be customized to the specific demands of individual radiologists at a single workstation or any workstation across the enterprise. PACS hanging protocols can be relatively simple (new studies on the right, older ones on the left) or quite complex. The system can define, for all users or for specific radiologists or clinicians, specific rules that determine which previous studies, if any, are retrieved for comparison and precisely how current and prior studies are displayed for interpretation. Images can be displayed, for example, in frame mode, which closely emulates film (nine images on one monitor), or in stack mode (a series of images displayed sequentially, much like viewing animation by flipping through a stack of cards). The need for these hanging protocols is even greater with more complex examinations, such as a large thin-section CT dataset in which multiplanar, three-dimensional (3-D), or maximum-intensity projection (MIP) views with variable slice thickness may be selected for current and comparison study.

The PACS at the BVAMC uses a series of algorithms for display on a multimonitor workstation. These are known as default display protocols (DDPs). The use of the DDP, which can be toggled off or on, was found to result in an increase in radiologist productivity of between 10% and 20%, depending on the imaging modality (Figure 6.2). In addition, radiologists reported less fatigue subjectively with the use of the DDP in comparison with electronic but manual selection of prior studies to be retrieved and manual (electronic) or nonintelligent placement of the images on the workstation. Reading times were also decreased somewhat by the reduced amount of time required to review previous reports. Using the PACS, previous

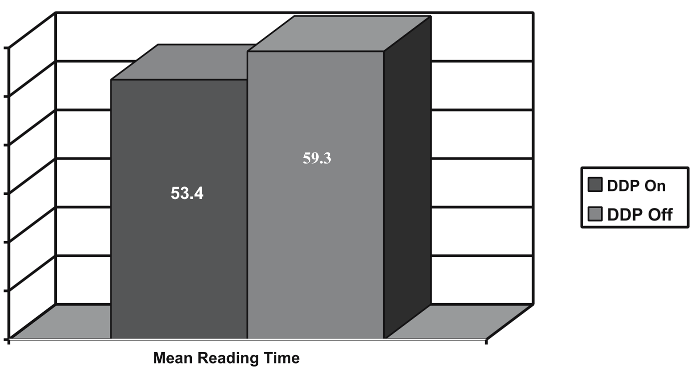

FIGURE 6.2

Radiologist reading times for general radiography decreased by 10% using the default display protocol.

reports are organized in chronological or another organized format to make review of priors rapid and their relationships easily understood.

THE INTERPRETATION PROCESS

Radiologist image interpretation speed has been only one of a number of factors that have resulted in increased productivity, but the workflow improvement that has been associated with PACS in this area has been significant. At the BVAMC, we found that radiologist reading times decreased by 19% in the interpretation of portable chest radiographs from the intensive care unit (unpublished data). Another study performed at our facility demonstrated that radiologists were 8% faster in the interpretation of musculoskeletal radiographs using computer workstations and computed radiography in comparison with interpretation using conventional film. Similarly, radiologists were found to require 15% less time to interpret CT examinations using a computer workstation than using film. This was, for the most part, associated with the decreased amount of time required to display images, particularly in multiple window/level combinations. The advantage of softcopy interpretation over film for CT studies was even greater for examinations in which there were previously performed CT examinations for comparison. This increased speed of CT interpretation was not associated with any decrease in the accuracy of interpretation; in fact, accuracy increased to a statistically significant degree. Others have documented similar decreases in total interpretation time.

WORKSTATION TOOLS

The retrieval of images to the workstation is only the first of several workflow steps in the interpretation of an imaging study. To extract as much clinically useful information as possible from the images, a number of steps may be helpful:

1. Images must be optimized with regard to window/level (brightness/contrast) settings. There is no optimal window/level for most images. Consequently, continuous dynamic adjustment of window/level settings is often necessary for a conventional radiograph (such as a foot examination). Alternatively, certain presets may be used (as would be typical for a thoracic CT).

2. The method of image display and navigation must be chosen. The simplest of these is static softcopy interpretation, with images displayed on workstations much as they would have been on view boxes. Frame mode is an example of this type of static mode in which images are displayed in a matrix similar to that typically printed to film. Stack mode displays images sequentially in a single window in a movie- or cine-like format. Linked stack mode, a further enhancement that synchronizes multiple stacked images within a single examination or across a current and one or more prior examinations, is increasingly available and utilized, although its value has not been adequately documented in the literature. Most recently, volumetric navigation of isotropic CT datasets permits review of images in any desired two-dimensional (2-D) or 3-D perspective, resulting in a separation of the manner in which images were acquired (the axial plane for CT, for example) from the way in which they are reviewed.

3. Images and portions of images can be zoomed or magnified.

4. Images can be viewed using MIP, which has been documented to be useful in the evaluation of blood vessels and lung nodules.

5. Thin-section images can be combined arithmetically to create a user-selected slice thickness that is a multiple of that reconstructed by the acquisition device.

6. Images can be arranged in a logical format to make it as easy as possible to compare various sequences (e.g., enhanced vs. unenhanced, or T1 vs. T2 vs. contrast-enhanced MR images) and to compare a current study with comparable images from a previous study.

7. Images can also be enhanced with tools, such as edge enhancement, smoothing or interpolation algorithms that "smooth" the image to give it a less boxy or "pixely" appearance, or those that enhance the ability to display a wide range of contrast on an 8-bit monitor or film.

8. Images can also be processed using more sophisticated techniques to achieve spatial frequency and image contrast optimization.

9. Additional tools can be implemented to aid in decision support, including computer-aided detection tools that have been successfully applied in mammography and in the detection of lung nodules on CT or conventional chest radiography.

Each of these steps depends to some degree on the preferences of the radiologist and on the demands of the specific study and modality. For many radiologists, both experienced and in training, one of the greatest current challenges is in identifying these preferences as the range of choices expands and technology evolves. The "intelligent" workstation and the PACS that supports it not only must be ready to customize different combinations of workstation tools to suit each user but must be configured to seamlessly integrate new software that enhances the interpretation process.

Current PACS workstations vary tremendously in the success of their graphical user interface and in the number of steps required to utilize these and other tools. Most workstations do a relatively poor job of optimizing radiologist workflow. The best of these workstations have a relatively simple (elegant) graphical user interface and require a minimum number of keystrokes and steps to retrieve, optimize, compare, and remove a study, and then proceed to the next imaging study. As the PACS industry continues to develop and mature, vendors are spending an increasing amount of time obtaining feedback and performing studies of radiologist workflow in the interpretation of imaging studies, which has resulted and will continue to result in improvements in the radiologist-machine interface.

We have found that the use of workstation tools by radiologists changes with increasing experience with the system. Radiologists have a tendency to use tools such as image zoom and magnification less frequently as they gain additional experience with the workstation. However, we have found that even experienced radiologists utilize the window/level adjustments in the majority of cases.

WORKFLOW TOOLS TO COPE WITH IMAGE OVERLOAD

The use of volumetric navigation has been accelerated by the rapid transition to the use of multidetector CT scanners. Radiologists around the world are finding other interpretation routines inadequate for the large numbers of images generated from these systems. A routine CT of the thorax using a multidetector system can generate 30 sheets of film each for lung, mediastinum, and liver settings. Even stack mode is inadequate for review of the 300 to 500 images acquired for a routine CT of the chest or the abdomen and pelvis and is even more so for the 1500 to 2000 images acquired for a CT angiography "runoff" study.

Several strategies are being investigated for dealing with this image overload. The most common is to acquire images using a multidetector scanner using thin-collimation and then reconstruct the images that are sent to the PACS using much thicker (e.g., 5- or 8-mm) sections, resulting in a 3- to 10-fold reduction in the number of images sent to the PACS. Additional reconstructions or renderings can then be performed by the technologists using a dedicated CT workstation. Unfortunately, this approach is unsatisfactory. It requires a large amount of additional technologist time, especially for angiographic rendering, analogous to the extra time required for technologists to produce films in multiple window/level settings. Because of the complexity and time required, technologists only perform this rendering in a small percentage of cases. In addition, the reconstructed images unnecessarily take up a good deal of archival, network, and workstation memory space.

Radiologists should have flexibility from case to case to determine whether the images should be reviewed in the sagittal, coronal, or oblique planes or using a 3-D perspective. Volumetric navigation frees the radiologist from the limitations of fixed-slice axial images. An image of the spine, for example, can be rapidly and interactively rendered and reviewed as a sagittal or coronal dataset at any desired slice thickness. The viewing perspective can be determined by the area being examined and the clinical history. The pulmonary arteries, for example, can be reviewed using relatively thick-slice coronal or oblique perspectives, with or without the use of MIP rendering. The colon, in our experience, is best depicted in the coronal plane, whereas the liver and spleen may be examples of organs best reviewed in the axial plane but may be improved with the use of MIPs. The vasculature of the thorax, abdomen, pelvis, and other areas may be optimally displayed according to their orientation within the body and are also probably best rendered as MIP images.

Although volumetric navigation has tremendous potential, it poses some unique and daunting challenges as well, especially the concern that we might be trading image volume overload for clinical image content overload. Our abdominal and thoracic subspecialists have asked whether they are now responsible for detailed reports of the musculoskeletal system and spine and of the individual vessels now visualized on a routine body CT study. Should they specifically and routinely comment, for example, on the renal arteries, aortic and iliac arteries, or superior and inferior mesenteric arteries? What are the implications of this on the time required to dictate a study?

Perhaps the biggest barrier to the transition to the use of volumetric navigation has been the lack of integration of this capability in the current generation of PACS workstations. It is not practical for a radiologist interpreting a study using a PACS workstation to walk over to a dedicated 3-D/multiplanar workstation for each case. Another challenge is the fact that image navigation is typically not a linear, sequential process like review of a set of axial images but may be performed in a more haphazard fashion, with a radiologist reviewing a portion of a dataset in one plane and other portions using other views, which could result in portions of a dataset not being reviewed at all.

The transformation of the radiology interpretation process will continue at a rapid pace. Although image navigation and enhancement will continue to improve (including better support for multimodality fusion such as positron emission tomography [PET]/CT), the next major phases will focus on decision support tools such as computer-assisted diagnosis (CAD) and cuing and intelligent applications of informatics. Computer-assisted cuing may take many forms, including an overlay in which microcalcifications are circled on a mammogram and lung nodules appear in a color that indicates their probability of malignancy. CAD programs will come into routine use in the next few years, especially in the detection of lung nodules and breast cancers. Clinical information from the electronic medical record, results of previous examinations, and clinical and imaging expert systems will be utilized to optimize image navigation, computer cuing, and CAD programs and to suggest diagnostic possibilities. Comparison with large computerized reference image datasets may also be utilized routinely by radiologists to facilitate more rapid and accurate diagnoses. These future additions to the armamentarium of the radiologist will also create additional challenges that will undoubtedly require the creativity and expertise of the medical imaging community.

CHANGING THE REPORTING PARADIGM

SPEECH RECOGNITION

The interactive workstation has facilitated one of the most obvious changes in radiologist workflow over the last decade: the way in which radiology reports are generated, reviewed, and relayed to the referring physician and to the medical record. Machine dictation of radiology reports and subsequent manual transcription were among the first "automated" elements in the radiology workflow. At the same time, manual transcription accounted for the main time lag between image acquisition and delivery of interpretation results to referring clinicians. As early as the 1980s, radiologists were considering the possibility that speech recognition techniques might be incorporated into the reporting process.

In the intervening 2 decades, speech recognition (sometimes misidentified as voice recognition) has become an integral part of the radiology workflow, with many institutions eliminating medical transcription positions entirely. Speech recognition has been investigated more closely than almost any area of digitalization for two reasons: it affects every imaging specialist, across modalities and subspecializations, and it has often been a "hard sell" to the radiologists who (in theory) would benefit most from its implementation. The literature on speech recognition is voluminous, with many reports of benefits in decreased needs for auxiliary staff, money savings, and time savings in turning around reports for delivery to physicians who ordered studies.

The process of acceptance of speech recognition technologies by radiologists has not been smooth. In part, this was because it was unfamiliar. More important, many radiologists perceived speech recognition reporting to be more difficult, more time consuming, and part of a slippery slope that seemed to be taking clerical tasks out of the hands of paid assistants and turning them into routine parts of the professional interpretation and reporting process. (They were, of course, correct in the last of these assumptions.) Efforts by vendors to simplify enrollment (the process by which an individual imprints his or her speech patterns on the system), increased use of report templates, well-executed training, and the introduction of innovative time-saving features have served to win over many who originally opposed the introduction of speech recognition. Advantages in report turnaround times, the ability to correct and redact reports at the time of dictation or subsequent time of choice, access to the report through the PACS from anywhere in the medical enterprise, and a tendency toward the production of shorter, more organized reports have bolstered support for speech recognition among radiologists. For those who use speech recognition in combination with structured reporting technologies, real-time savings and workflow advantages are being realized.

STRUCTURED REPORTING

Structured reporting is not new. Since the first "roentgenology" reports in the late 19th century, imaging specialists have sought to simplify their work by eliminating unnecessary duplication from report to report. In the earliest days, there were fill-in-the-blank reporting forms. Later, radiologists read from templates as part of dictated reports, filling in the specific information for each patient. Today, templates and macros integrated into the electronic radiology reporting process allow each radiologist to customize routine reporting and enter large sections of reports using only a few keystrokes. Moreover, templates can be used in "batch mode" for high-volume study reporting.

Structured reporting is now being combined with other workstation interpretation tools to yield what some have called the radiology report of the future: a multimedia package that includes not only the traditional report but embedded annotated images, lists of and links to additional informational and visual resources, and cues and guidance provided by computer-aided decision support strategies. The possibilities for entirely transforming both the radiology reporting process as well as elevating the level of content in reports are truly exciting. The challenge will lie in exploring these possibilities in ways that enhance rather than add to the work of the radiologist.

THE EFFECT OF CHANGED RADIOLOGIST WORKFLOW ON ENTERPRISE INTERACTIONS

REFERRING PHYSICIANS AND CLINICIANS

The transition to filmless operation at the BVAMC was associated with an 82% reduction in in-person consultation rates in general radiography and a 44% reduction for the cross-sectional imaging section, despite an increase in the volume of studies (Figure 6.3). This decrease in the general radiography consultation rate from 13% (pre-PACS) to 2.4% was greater than we had anticipated. The ability of clinicians to remain in patient care areas and not make time-consuming trips to the radiology department has significantly changed their workflow as well. The direct consultation process has been

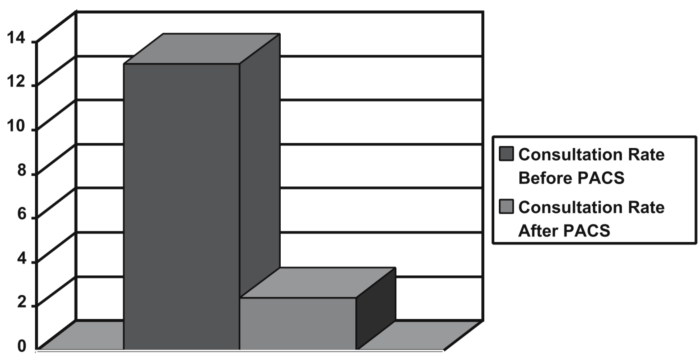

FIGURE 6.3

The advent of PACS and image distribution throughout the enterprise brought an 82% reduction in clinical consultations on general radiology cases.

transformed into an electronic process that relies to a greater extent on digital annotation of images viewed at workstations, access to digital dictations over the telephone, and increased use of e-mail and physician alerts available in the EMR.

The increased frequency of image review by physicians at our institution was associated with an unexpected increase in radiology utilization rates and, perhaps ironically, in a consequent increase in overall radiology workload. The number of studies ordered per patient admission at our institution increased by 43% after the implementation of digital distribution of images and reports, compared with a 0% increase for the rest of the VA hospitals throughout the country during the same period. Outpatient utilization at our institution increased by 21% during the same period, while national VA outpatient utilization decreased.

Clinicians adjusted with great alacrity to decreased report turnaround times after radiologists began reading studies within a few minutes of acquisition and came to expect these accelerated turnarounds as a part of radiology department services. Ninety-eight percent of clinicians surveyed at the BVAMC indicated that the use of the PACS contributed to more effective use of their time. This was largely due to the improved access to current and previous imaging studies and convenient availability of access to these images in patient care areas. Clinicians indicated that they accessed the PACS 3 to 5 times per day, with 22% accessing the system more often. The average estimate of the amount of time saved because of the PACS, according to clinician surveys, was approximately 50 minutes, suggesting that the system substantially enhanced their workflow. In some institutions, clinicians can now access the digital dictation system by phone for radiology reports as well as read near real-time reports distributed after speech recognition sign-off on the PACS.

A not inconsiderable amount of concern has been expressed (for the most part in editorials and not in data-driven studies of the problem) about the result of the changed radiologist workflow and output on the quality of interaction with clinicians. It is true that the number of face-to-face interactions over specific cases has been greatly diminished in the all-digital radiology department. However, other technological innovations may be serving to compensate for what some perceive as the radiologist's diminished presence in the diagnostic and treatment equation. For example, radiologists are much more likely to use the telephone to discuss urgent findings, such as a pneumothorax in the intensive care unit (ICU), than before the transition to filmless operation. This is because the decreased time between study acquisition and review makes it much more likely that the radiologist will be the first to review the images. Thus, many clinicians are receiving real-time reports from their colleagues in radiology about their most urgent and/or problematic cases.

Moreover, in a reversal of the old consultation pattern that had the clinician coming to the radiologist, the radiology department is now, in effect, distributing itself throughout the enterprise for immediate access to a wide range of practitioners. PACS workstations with integrated access to the RIS in surgical suites, ICUs, emergency departments, and satellite clinics have eliminated an entire segment of routing workflow and put the results of the radiologist's work at the immediate service of the clinician where he or she needs it most. DeSimone et al. evaluated the impact of PACS on clinical practice in the ICU setting and showed statistically significant reductions in time to perform clinical actions after the diagnostic examination. Using PACS, significant alterations were demonstrated in the processes of obtaining radiologic information, viewing exams, and consulting between ICU physicians and radiologists. The results of the study suggest that a PACS has a major effect on both patient management and radiology department workflow in the ICU setting.

One example of this improved workflow has been in the communication of abnormal findings by emergency room (ER) or emergency department physicians. One study reported that even in a non-PACS environment, the introduction of a single workstation in the ER reduced time to delivery of the radiology report from an average of 40 to 16 minutes by eliminating printing and transport. One of the challenges in a paperless and filmless environment has been the communication of preliminary impressions of ER physicians to radiologists. This has been addressed at our institution by giving the ER clinicians the ability to view a field on their workstation that allows them to determine whether a study has been interpreted by a radiologist. For those studies that have not yet been dictated by a radiologist (a minority during the working day) by the time the ER physician reviews the imaging study, the ER physician can type a preliminary impression directly into the PACS electronic display in the section that lists the reason for the study. The radiologist is then able to alert the ER physicians when there is a discrepancy between their preliminary impressions and the radiologist's interpretation of the images.

These advantages, when combined with the incremental positive effects of collegial e-mails, voice mails, augmented teaching sessions and conferences, and the generally increased utilization of a growing number of different imaging services, suggest that the benefits of digital imaging will enhance rather than detract from the radiologist's standing in the larger medical enterprise.

WORKFLOW AND MULTI-INSTITUTIONAL PACS

The market forces that have created the strong impetus to increase efficiency and productivity have also fostered the formation of imaging networks in which large radiology groups provide imaging services for multiple facilities. This can result in substantial savings by taking advantage of centralized administration, scheduling, and staffing and economies of scale in supplies, furniture, and even imaging apparatus. However, imaging networks pose challenges that include issues related to distance, different equipment and information systems, communications, and personnel with different "cultures" and a variety of approaches to the departmental operation. Optimizing RIS and PACS workflow management can be difficult across such a disparate landscape but carries with it a number of long- and short-term benefits. Radiology coverage and subspecialty expertise can be shared across multiple hospitals. This has been particularly helpful in situations in which one or more radiologists provide overnight coverage for multiple facilities. The ability of a single radiologist to provide network coverage across multiple facilities has been a major impetus for many radiology groups to install teleradiology systems or PACS. Such efforts have their own difficulties in tracking multiple patient identification systems, interfacing adequately with several vendors, and dealing with communications problems between hospitals with different systems. Despite these challenges, the potential workflow advantages of a multifacility shared or complete virtual radiology department are tremendous, both to the radiology department and to the clinician. The potential to share the radiology caseload in a more effective manner made possible by PACS in a single institution is even greater in a wide area networked virtual department, particularly with regard to subspecialty expertise. The ability to access images obtained at other institutions within the network can eliminate many of the delays associated with film transportation as well as decrease the number of unnecessarily repeated examinations.

In the VA Maryland HealthCare System, the transition to a wide area network virtual radiology department has resulted in savings of approximately $800,000 to $1,000,000 per year, largely in personnel costs. The network is set up in a hub-and-spoke configuration in which images are sent to Baltimore for storage on the VA Baltimore commercial PACS and are then made available throughout the healthcare network. This hub-and-spoke configuration is also used for the HIS and RIS, resulting in the need for a central computer system in Baltimore and reliable high-speed networks connecting the facilities. This "central" architecture for the PACS has been successful in our environment, with four facilities connected to the BVAMC.

Perhaps the biggest challenge with regard to integration of multiple healthcare facilities is the need to have a common, agreed-on method for exchange of patient images and other patient information. Recent federal government mandates in the United States have hastened efforts to codify standards that would make processes such as patient identification, modality worklists, and management of image interpretation automated in a multi-vendor, multi-HIS-RIS hospital system or between two or more healthcare systems. At the same time, such improved communication is under new restrictions designed to protect patient privacy. The IHE initiative is at the forefront of efforts to bring modality imaging vendors to the table with both RIS and HIS vendors to formulate solutions to these challenges. True integration across one or multiple healthcare enterprises is a much more practical and easily achievable goal than it seemed only a few years ago.

THE READING ROOM ENVIRONMENT AND WORKFLOW

One of the more hotly debated issues with regard to optimization of radiologist reading performance and workflow has been the question of the optimal number of monitors that are required when using a PACS workstation for various modalities such as computed radiography, CT, MR, sonography, and so on. This is particularly important given the substantial expense of these monitors and the high percentage of the total workstation cost associated with the number of monitors. At the BVAMC, we performed a prospective study of the impact on radiologist performance and levels of fatigue as a function of the number of monitors. We found an approximately 25% increase in radiologist reading speed for a 4-monitor in comparison with a 1-monitor workstation in the interpretation of portable chest radiographs performed using computed radiography when we took into account the number of prior studies reviewed. Interestingly, there was a decrease in the number of historical studies reviewed as the number of monitors decreased. There was very little difference in the amount of time required to read the studies when comparing a 2- with a 4-monitor workstation, and the largest increase in performance was seen between a 1- and a 2-monitor workstation. Although we have not yet performed this study, our expectation would be that the use of stack mode for CT and MR studies would substantially decrease the added value of 4- or even 2-monitor workstations for the interpretation of these studies. Anecdotally, this seems to be particularly true when the workstation permits images from multiple examinations to be linked according to anatomic section, which facilitates easy comparison of current and previous cross-sectional images.

The number of monitors is only one factor in designing an ideal radiology reading room, a goal that has only recently been appreciated as a potential contributor to improvements in radiology workflow. Despite transitioning to filmless or almost-filmless imaging, most institutions maintained without question the traditional configuration of the film reading room. And, given the extensive attention that has been paid to PACS monitors and workstations, surprisingly little attention has been paid to the radiologist (and clinician) reading room environment. Our research at the BVAMC has indicated that a number of factors, including monitor and ambient room lighting levels, among others, play a critical role in radiologist productivity and fatigue. We found that radiologist performance decreases significantly and that fatigue increases as monitor brightness drops or as ambient room lighting increases.

Several research laboratories have now documented the importance of additional factors, such as workstation chair design, the availability of individual lighting and temperature controls, and room acoustics, on radiologist performance and fatigue. Architects, who have responsibility for designing workplace environments, have also recognized the vital role of workstation ergonomics.

AUDITING THE RADIOLOGIST WORKFLOW PROCESS

Every imaging department, regardless of the quality of staff, integrity of findings, or excellence of technical facilities, shares a usually unspoken secret: their way of doing radiologic work evolved over time and without a comprehensive workflow design strategy. Even the most carefully planned of all-digital departments still contain elements of workflow that are purely vestigial. With the rapid turnover of technology and personnel, potential workflow improvements are available to every department and could not only realize time and money benefits but enhance patient outcomes and quality-of-work issues for both radiologists and technologists. The problem, of course, is in identifying areas of potential improvement before the next round of change brings in new variables.

The digitalization of the entire acquisition, processing, reading, reporting, and archiving process in radiology presents extraordinary opportunities for quantifiable study. Some variables are easily extracted from the information technology record (speech recognition dictation and correction times, for example), whereas others require more definition (such as reports on how many times a radiologist looks at a specific type of image and/or refers to others).

Radiologist workflow cannot be studied without adequate tools to measure performance (including the use of workstation tools of all types), accuracy, comfort, fatigue, and satisfaction. We have recently worked with industry to extend error logging tools built into workstation software into more comprehensive workstation "audits" that generate very large amounts of data (approximately 50 pages per minute) and have used these to produce detailed analyses of radiologist interpretation workflow. These audit databases constitute as yet untapped gold mines of fascinating data and should lead to new insights into the ways in which radiologists utilize conventional and multiplanar 3-D workstations in rendering routine diagnoses. These types of investigations should provide the data that will drive future workstation enhancement and influence the next generation of intelligent (or less dumb) workstations that analyze each radiologist's interpretation habits and then adapt responses to help the radiologist achieve enhanced efficiency and accuracy.

CONCLUSION

The most frightening and most promising word that currently defines radiologist workflow is "more": more images generated from more modalities to be read at a faster pace, more tools that support image processing and reporting, more ways to shape interactions with others in the medical enterprise, and more possibilities to enhance diagnostic capabilities and the well-being of patients. The problem, of course, is that there are no more hours in the day.

The importance of an understanding of workflow for RIS and PACS vendors has resulted in substantial improvements in the development of intelligent software and use of integration with other information systems. This trend will undoubtedly continue. Universal adoption of integration protocols such as the IHE and standards such as DICOM and HL7 will continue the trend toward the elimination of paper and will result in further reductions in the number of steps in the flow of information to and from the imaging department. Computer-assisted detection will provide both a prescreen and a double-read for radiologists in the interpretation of a much wider array of imaging studies. Workstation innovations will continue to improve on the ways in which radiologists can access and compare current and previous examinations and will permit a greater degree of interactivity with the images themselves. New strategies will doubtless be offered for dealing with increasing datasets.

The challenge, of course, is to be able to incorporate such new strategies into existing PACS configurations and to evaluate their utility in both workflow benefits and diagnostic outcomes. PACS are well beyond the "early adopters" phase and have become an integral part of all aspects of radiology workflow. In the process, the pace and nature of the radiologist's work has changed profoundly, and we are only now beginning to investigate the effects of these changes and the ways in which future change may continue to alter training, practice, and workflow.

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