Reinventing Radiology in the Digital Age
Part II. New Directions and New Stakeholder Value

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Digital imaging devices, computer-based image-management systems, and radiology information systems (RIS) are the three building blocks that serve as the foundation for the all-digital practice of radiology (1). In the first instance, these digital technologies have been used simply to replace the analog imaging systems and the manual information and film-handling systems, used historically for management of the radiology work process, with digital and computer-based systems. More important, these building blocks have rapidly become the enabling platform technologies for radiologists and imaging scientists to use in exploring new and potentially transformational directions. In the new digital universe of medical imaging, opportunities abound to create entirely new clinical applications, new practice models, and new ways of creating value for stakeholders that were unimaginable only a few years ago.

New Practice Models in the Digital Age

After World War II, hospitals morphed into medical centers and then into regional delivery systems, often with multiple locations scattered throughout a geographic region and even beyond, which created new challenges for departments of radiology. When I chaired the Department of Radiology at the Henry Ford Hospital (Detroit, Mich) in the 1980s, we had three large satellite ambulatory care centers in the communities surrounding Detroit and another dozen neighborhood health centers, all with imaging capability of one kind or another. Fully one-third of our 360 000 annual examinations originated off the main campus, and we were constantly shipping film hard-copy folders around the delivery system to the limited number of places where staff radiologists were located. Turnaround times were slow for the remote clinics without radiologists present, and I dreamed of the day when we could digitize everything for electronic distribution and stop having to be in the shipping business.

From a practical standpoint, however, it turns out that the mere technical capability of sending images from point A to point B, as in early implementations of teleradiology, does not support a robust multiscalable radiology practice model for several reasons. Early versions of teleradiology were limited by bandwidth and were able to handle only limited data sets within a reasonable time frame (2,3). In early implementations of teleradiology, information about patients was typically telephoned (later, faxed or e-mailed) (4,5) to the radiologist, and there was no ability to remotely query an image archive for prior examination results or to query a hospital information system (HIS) or RIS for correlative supporting data or prior reports. Report delivery suffered the same shortcomings in reverse.

Most teleradiology systems in place today, including those used by commercial companies to provide supplementary coverage for radiology practice groups, still suffer from one or more of these shortcomings (5). It is challenging to run conventional teleradiology systems at a high level of throughput; they are very human-resource intensive because the image-management systems and the information systems at the receiving site are typically not fully integrated with the respective image-handling and information systems at the location of origin of the examinations, so each case requires some level of hands-on administrative intervention. The original implementation of teleradiology, as the point-to-point transmission of image data and separate handling of other information about the patient and the examination, was cumbersome at best.

The availability of high-speed communications links supporting wide-area network architectures (6–8) has been the breakthrough to the establishment of the kinds of distributed practice models needed in radiology to meet the needs of regional delivery systems. The terms wide-area picture archiving and communications systems (PACS) or distributed PACS are reflective of the architectures now available for image-management across multiple locations, and the transition from first-generation teleradiology concepts to wide-area PACS provides great flexibility for radiology practices.

With high-speed links and wide-area connectivity in place, each practice location can function as a fully integrated node on an institutional or corporate network rather than as a separate, out-of-network, point-to-point connection. In this construct, all the functional elements of the host PACS, RIS, and HIS exist at each practice location. The site of origin of a given examination is transparent to the radiologist, since all image data—including data from prior examinations and all patient records—are seamlessly available as if the radiologist is working within the host institution.

At Massachusetts General Hospital (MGH), we faced the need a few years ago to place radiologists off campus in several small imaging centers to comply with supervision requirements, yet none of the
centers generated enough work in any given subspecialty discipline to justify the presence of a full-time staff radiologist. The original choices were to give up our commitment to subspecialization off campus or to work inefficiently. This is no longer a problem with wide-area PACS in place. The off-site radiologists simply practice in parallel with their colleagues on the main campus and, in some situations, are not even assigned to interpret any of the studies that have originated where they are physically present.

What initially looked like a blow to practice finances and efficiency has turned out to be a great success on both counts because of the ability to work with seamless connectivity in multiple locations. Radiology is probably in the best position of any specialty to meet the requirements of contemporary regional delivery systems for multisite practice coverage and integration of data from multiple geographically dispersed sources.

Communication and Clinical Practice Support

A common flaw in health care information systems is that they are typically designed by and for the providers generating the respective information and not for the physicians who must use the information for the care of their patients. First-generation designs for radiology PACS and RIS share this flaw. These systems were developed primarily to make the practice of radiology more efficient and of higher quality, but they were designed "from the inside out" without sufficient regard to the needs of users outside radiology departments. Most early PACS were not designed for use with the Internet (8) and could not readily be used to send images to physicians' desktops. Some early-generation RIS implementations provided remote access to reports on individual patients but in general did not help clinicians manage the flow of requests and reports related to their practices or help them schedule examinations directly without some kind of telephonic or written communication.

For many years, we have used the term the electronic round trip at MGH to capture an idealized implementation of information flow and communication within departments of radiology and between those departments and their clinician stakeholders. The overarching goals of the electronic round trip are to extend the reach of the all-digital practice of radiology beyond the department to the entire enterprise, including computer-aided entry and results reporting, and to eliminate telephonic and handwritten communication. Another specific objective in the electronic round trip is to never have to perform keystroke reentry of a patient's name or demographic data at any step in the work process once the patient is selected by the referring physician. To achieve this, all steps of the work process must be electronically integrated and an institution's registration system or master patient index be used as the single "source of truth" (1) for patient demographics.

To achieve the electronic round trip, we have developed a Web-based order-entry system at MGH linked to both the hospital's master patient index and the RIS. The ordering physician selects the patient of interest from the HIS and the desired examination and appointment time directly from the order-entry system; no phone calls or faxes are required. Patient demographics and study information are transmitted electronically to the RIS and are archived. On the day of the appointment, relevant information about the patient and the desired study is retrieved and forwarded electronically to the designated imaging device. After completion of imaging, the patient-related information is forwarded along with the images to the PACS and is called up during interpretation by using a voice-recognition system. Images and reports are then available electronically on physicians' desktops via the hospital network and outside the hospital via a virtual private network.

The level of systems integration embodied in the concept of the electronic round trip greatly reduces keystroke errors, and the combined desktop availability of order entry and receipt of reports and images makes practice more efficient for clinicians. Among other benefits, the simple step of creating a direct link from the RIS to the imaging device at MGH has reduced by a factor of four the number of examinations that require any kind of administrative intervention to correct errors. The ability of physicians to schedule examinations directly has led to a reduction in telephone calls and faxes to the Department of Radiology scheduling office, thereby reducing process steps, communication errors, and the time required for all involved parties.

Once a robust link is established between the RIS and physicians' desktops, a number of other services can be offered to improve practice efficiency and create value for clinicians. For example, at MGH an individualized database is created for each physician as part of the order-entry system; this database summarizes the status of all recent examinations ordered for each physician's patients. Information available includes the scheduled date of the examination, completion status, cancellation ("no-show") status, whether the report is available yet, and an indicator of whether the report has been read by the physician. Reports and images are directly accessible from the patient list by means of a single keystroke.

Clinicians at MGH use this database as a "tickler file" to keep track of all of the imaging studies they have ordered and the flow of results and to make sure patients have kept their imaging examination appointments. These are challenging issues for clinicians, who have grappled with them in dozens of ad hoc and mostly unsatisfactory ways in the past.

We are now extending the practice support system to include special Health Insurance Portability and Accountability Act–compliant e-mail alerts of important findings; this will introduce redundancy in communicating these findings and establish incontrovertible documentation that communication of results has been accomplished. The e-mail alert subsystem records the date the message was received by the referring physician and is periodically reviewed to make sure all messages have been read. Short of proving that a password-protected file has been opened by a specific individual with this kind of electronic system, there has been no practical iron-clad way for radiologists to prove receipt of reports, which leaves the radiologist vulnerable to claims of "failure to notify" in malpractice suits (9,10).

The electronic round trip offers the opportunity to improve quality and to reduce practice costs and malpractice risks by improving the accuracy and integrity of the exchange of data, including documented communication of results, and by streamlining work processes both inside and outside of departments of radiology. Busy clinicians who experience radiology "from the outside in" welcome the added value derived from the electronic round trip and its associated practice support capabilities.

Decision Support and Just-in-Time Knowledge Delivery

Rapid increases in the use of medical imaging procedures, especially high-technology cross-sectional procedures, has galvanized the insurance industry in

16 • Radiology • October 2005

Thrall
the United States to seek methods to stem the growth of their use. A common approach is to require referring physicians to obtain prior approval for more costly examinations, often by calling a commercial company that then becomes the arbiter of whether a study can be performed. This approach is aggravating, requires extra uncompensated time for referring physicians, and can result in hospitals and radiologists not being paid for their work if approval is not obtained according to protocol.

Rather than accept the toll-free telephone number approval paradigm, the Partners HealthCare System (PHS), an integrated delivery system in eastern Massachusetts with seven hospitals and over 3500 affiliated physicians, implemented two point-of-care decision-support systems, which have been accepted by one payer in lieu of the use of the payer’s own contractor for examination approvals. At MGH, the decision support function is integrated into the Web-based order-entry system described earlier.

After a physician has designated the desired examination and reason for its performance, the MGH system assesses appropriateness against a database of criteria developed at MGH through expert panels. The American College of Radiology has also developed a set of appropriateness criteria (11). The process occurs in real time, and the score is immediately shared with the referring physician along with the appropriateness scores for other types of imaging procedures that could be performed for the same indication. For marginal and low appropriateness scores, “hot links” to summary information about optimum use of imaging are provided, as are links to articles in the medical literature. An MGH radiology department phone number is also provided if direct consultation with a radiologist is desired.

Initial feedback from clinicians has been very positive. They appreciate being alerted to the fact that a different examination might be more effective. They use the “just-in-time” point-of-care availability of background information to improve their understanding of when to use different methods, and they especially appreciate not having to call a toll-free number, where they are likely to be put through an anonymous time-consuming process. The addition of practice-support and decision-support functions to an RIS transforms the RIS into a far more complex entity, with multiple layers of new applications and the opportunity to create important new value for all stakeholders.

**Data Mining**

A byproduct of years of collecting medical images and associated patient data in digital form is the creation of enormous databases in departments of radiology that can be searched for administrative, quality improvement, research, and educational purposes. It is easy now in many departments to query the RIS for subject matter and then to retrieve the associated imaging studies electronically from the PACS. Links to the HIS and other departmental information systems quickly yield the kinds of data we used to painstakingly extract from patients’ charts.

It cannot be overstated how greatly this facilitates putting presentations together, developing teaching files, and collecting material for research studies.

For teaching files, instead of collecting a few examples of something as we typically did in the past, it is feasible to have dozens or even hundreds of proved cases online, so that residents and fellows can access literally months or years worth of material efficiently in a short period. This ability is particularly crucial for teaching practicing radiologists new methods like virtual colonography and angiography of the coronary arteries, where it is necessary to look at large numbers of cases to build experience.

These initial applications for mining databases in radiology have been fruitful but are fairly obvious. However, the combination of the sheer amount of searchable data available and the development of new data mining tools is opening entirely new avenues of investigation. For example, a number of computer-based artificial intelligence systems (12–14) have been developed for the analysis of radiology reports. A rules-based system developed by Keith J. Dreyer, DO, PhD, at MGH was designed to determine whether a radiology report contains positive findings or negative findings and, if positive, to identify the key finding. The program also determines whether the radiologist made a recommendation or not and, if so, whether it was for another imaging test or for something else.

The power of this program is the ability to assess the performance of radiologists and referring physicians in terms of a host of important parameters. For example, radiologists can be criticized for self-referral if they recommend an excessive number of follow-up examinations, but this observation may also be an alert to insecurity on the part of a radiologist who might benefit from additional training in a particular area. Likewise, clinicians who do not understand the proper use of imaging may have higher rates of negative studies. This can be tested by running the study data through a decision-support system to determine appropriateness, with the possible hypothesis that a low score would be associated with a higher negativity rate and a high score would be associated with a lower negativity rate for a given indication. In this context, higher recommendation rates for additional imaging might also logically be expected for cases with low appropriateness scores. Each parameter can be tested against the performance of the referring physician, as well as against that of the radiologist.

By systematically applying such a data mining program to the performance of all involved parties, performance can be tracked over time, institutional or individual idiosyncrasies can be uncovered, and feedback can be provided if substantial deviations from best practices or interpractice variations are detected. Such programs could be invaluable to our efforts at understanding how to manage utilization, through the program’s ability to track key parameters of physician and institutional performance over time.

**Image Processing and the “Michelangelo Principle”**

The renowned Renaissance sculptor and painter, Michelangelo, famously wrote, “The greatest artist has no conception which a single block of marble does not potentially contain within its mass” (15). In his view, it was the sculptor’s function to release forms imprisoned in matter. In the Galleria dell’Accademia in Florence, Italy, there are several unfinished works by Michelangelo known as the “prisoners in marble.” It is quite impressive to examine these works—to see arms and torsos that appear to be emerging from solid stone. One could swear that the rest of the figure is already there and is simply waiting to be released from imprisonment by having the extraneous marble chipped away. Michelangelo’s philosophic observation is a powerful metaphor for contemporary radiology: indeed, one of the most profound advances in imaging science is the development of a host of methods to extract medically valuable information “imprisoned” in the enormous blocks of data routinely obtained in cross sectional imaging. I have come to think of this as the “Michelangelo principle.”

Tissue segmentation routines, novel three-dimensional rendering methods,
and fusion and subtraction of data from different acquisition sets are increasingly used to separate tissues and organs of interest from surrounding structures to facilitate display and analysis and to extract the maximum information content from any given block of image data. Functional magnetic resonance imaging, which has revolutionized neuroscience, is wholly predicated on image postprocessing.

When image processing is applied to extract more and better information, more value is generated per unit cost of acquiring the images and per level of risk to the patient from exposure to radiation or contrast agents. The potential net effect on radiology of image processing is not marginal or incremental: It is transformational; but it will require new work processes and systems for the full benefits to be realized. Computed tomographic (CT) angiography serves as a useful generic example for the benefits of image processing. CT was a stunning breakthrough, but now, with multi-detector row CT, it has become increasingly possible to replace conventional angiograms with CT angiograms. Where applicable, CT angiography costs less to perform and may expose patients to less radiation and contrast media than does conventional angiography. CT angiography requires less time to perform and generates more kinds of information than does conventional angiography; therefore, CT angiography nets a near perfect score for delivering more value across all of these important parameters.

To realize the full potential of image-processing methods, new strategies and new work processes will be necessary in departments of radiology. It is not a matter of simply having images in digital form. Acquisition protocols need to be tailored to facilitate later application of image-processing algorithms, and a system for routing data sets to image-processing workstations needs to be put in place to facilitate high-volume production. Moreover, radiologists are generally too busy to take the time to perform complex renderings, and there is essentially no professional reimbursement available for the processing step; thus, a new job category for specially trained personnel needs to be introduced in radiology to perform image-processing of any substantial scale.

Image processing offers the potential for transformational change by reducing risks to patients and costs to the health care system while creating incredible new value by delivering information otherwise inaccessible in image data sets. Many departments of radiology are failing to realize these benefits and radiology is caught in a “catch-22.” Without the necessary technical infrastructure and dedicated human resources in place, it is difficult to realize the benefits of image processing; and without demonstration of the benefits, hospital administrators are reluctant to commit the necessary resources and payers are reluctant to reimburse. The radiology community must do a better job of making its own commitment to high-quality image processing and of igniting interest and support from hospital administrators and the payer community.

Conclusions
No short summary can capture even a fraction of what lies in our collective digital future. Indeed, each example of a new direction offered in this article itself branches in many additional directions, and none of these stories will be completely told for years to come. Newcomers to radiology and medicine will increasingly accept that work in an all-digital environment is intrinsic to radiology, and they will not give the barriers to its original accomplishment a second thought. Instead, they will be busy forging their own new directions.

References