There are rapid changes occurring in the health care environment. Radiologists face new challenges but also new opportunities. The purpose of this report is to review how new informatics tools and developments can help the radiologist respond to the drive for safety, quality, and efficiency. These tools will be of assistance in conducting research and education. They not only provide greater efficiency in traditional operations but also open new pathways for the delivery of new services and imaging technologies. Our future as a specialty is dependent on integrating these informatics solutions into our daily practice.

Key Words: Radiology Informatics; PACS; RadLex; decision support; image sharing.

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The health care environment is undergoing rapid change, whether secondary to health care reform (1–3), natural organic changes, or accelerated technological advances. The economics of health care, changes in the demographics of our population, and the rapidly evolving socioeconomic environment all contribute to a world that presents the radiologist with new challenges. New models of health care, including accountable care organizations, are emerging (4). Our profession must adapt; the traditional approach to delivering imaging services may not be viable. Despite the challenges, there are new opportunities presenting themselves in parallel. There are new and exciting information technologies (ITs) to offer our patients that can contribute to improving their health and that can position our profession to better tackle the challenges that lie ahead.

We will argue that new informatics tools and developments can help the radiology profession respond to the drive for safety, quality and efficiency. New research realms, both clinical and molecular, require sophisticated informatics tools. The health of the individual and an emerging focus on population health require IT solutions. We will start with a description of some fundamental informatics building blocks and progress to explore new and rapidly evolving applications of interest to radiologists.

A BRIEF LOOK BACKWARD

Radiology information systems (RIS) and picture archiving and communications systems (PACS), commonplace tools, are relatively recent developments. In 1983, the first American College of Radiology (ACR)–National Electrical Manufacturers Association (NEMA) Committee met to develop the ACR-NEMA standard (5), first published in 1985. In 1993, the rapid rise in the number of digital modalities and the parallel development of robust networking technology prompted the development of digital imaging and communications in medicine (DICOM) 3.0 (6).

Before RIS and PACS, consider how one viewed images, including cross-sectional exams of several hundred images. How were they displayed, archived, and moved about a department? We had film, dark rooms, light boxes, multi-changers, and film libraries requiring numerous personnel. How were copies provided for consultation? How did clinicians see the exams they ordered? Historical exams were often stored off site and not available for days. Exams were often “borrowed” and out of circulation or out right lost. How did one manage an office or a department, schedule exams, and bill for one’s services? These steps took place at a much slower pace than today.

Our new technologies have been “disruptive”. Certain jobs have disappeared (eg, file room clerks). The number of “schedulers” has usually diminished. The number of radiologists required to read a defined volume of exams has diminished, as PACs has resulted in increased productivity.

Into the Future!

We are in the midst of another paradigm shift. The rapid emergence and improvement of networking technologies are fostering this change. “Cloud computing” encompasses new technologies and services that are often the basis for the developments that we will discuss here (7–9). This term
encompasses a wide variety of services that are available over a network, often the Internet, and can include access to hardware platforms and applications. In health care, security and confidentiality are of particular importance. Cloud computing has started to strongly influence the world of radiology. In addition, wireless technologies, including smartphones and tablets, are quickly becoming tools used daily by radiologists and clinicians. Though we will not deal extensively with portable devices, one should recognize that many of the applications we describe here will find their way onto such platforms.

There is also a rapid increase in processing power available at a reasonable cost. This has enabled several technologies to appear at our desktops as well as on portable devices. A standard desktop computer can deploy voice recognition dictation systems with self-editing. Postprocessing solutions can be run on off-the-shelf equipment. These are services that required extremely expensive processing 15 years ago and were affordable to only a few. Many applications are being delivered as “server-side” solutions. Here, the workstation (or local client computer) almost becomes a “dumb terminal,” with most of the processing performed on a more powerful central server. The end-product is distributed to the local workstation. Server technology itself is rapidly changing. We are in the era of the “virtual machine”; one server hosts the equivalent of multiple stand-alone servers, optimizing the processing power of that single device.

**Radiology Practice: Current State and into the Next Decade**

We order, schedule, interpret, report, archive, bill, and share (exchange) the data we generate. We then close the circle by performing quality analytics and research on this data to improve our performance and advance our knowledge. We educate trainees and certified radiologists. Table 1 lists these processes and some of the informatics tools used to perform these tasks. We will review each of these activities, starting with the informatics tools that enhance our abilities to address the challenges we face.

**INFORMATICS TOOLS: THE FUNDAMENTAL BUILDING BLOCKS**

Here we will discuss the technologies used to build radiology IT solutions. Many of these will reappear later as we discuss specific solutions and their role in a radiology department or office.

**Standards**

Radiology IT developments have been enabled by the existence of standards. Not only must the standards exist, but the broader community must agree to use them. PACS could not have happened without the ultimate general acceptance of the DICOM 3 standard. Digital modalities existed, computed tomography (CT) and magnetic resonance imaging, before the firm entrenchment of DICOM. However, the archival and transport of those images were manual and chaotic until vendors uniformly subscribed to this standard. The same applies to radiology information systems (RIS). Health Level Seven (HL7) is the means of communicating much of the textual and numeric data, including demographics and reports. One vendor’s system can be interfaced to another’s because of these standard protocols.

While HL7 and DICOM 3 are probably the best known standards in our industry, there are other standards that systems use to provide interoperability. Sometimes there are multiple standards available to accomplish a given task. Engineers are familiar with all the relevant standards but historically have needed to build custom interfaces to allow systems to exchange information because the standards were not uniformly adopted. Integrating the Healthcare Enterprise (IHE) (10) is an organization with the goal of achieving transparent interoperability. IHE has multiple domains that examine common health care workflows and the available standards. Voluntary collaboration on the part of vendors and end-users results in the development of “IHE profiles.” These profiles describe a means of applying a group of standards to a given workflow. When vendors agree to follow these profiles, the result is transparent interoperability between systems (11). This is true plug-and-play functionality resulting in reduced costs for everyone.

**Standardized Terminology**

We need a standardized vocabulary (also called terminology or lexicon) if we are to develop smart systems capable of executing transactions, interpreting reports, and performing data mining. Some examples will illustrate the need for a radiology lexicon/terminology.

How can we measure the report “turnaround time” for radiologists in a practice? Today, this is difficult without a standardized terminology. Does “turnaround time” refer to the time from order entry to final signature or exam completion to the time of a preliminary dictation or some other combination?

This became a problem for the ACR in establishing its Dose Index Registry. The ACR wished to collect and compare dose data regarding “head CTs” from participating radiology practices. The ACR discovered that more than 1400 names were associated with “head” or “brain” and applied to what is essentially the same CT examination of the “brain” from 60 facilities (personal communication on 10/8/2012, Richard L. Morin, PhD, FACR, Department of Radiology, Mayo Clinic, Jacksonville, FL). A standard terminology would help resolve this problem. The terminology might identify some preferred terms, but when many exist a terminology identifies synonyms (12). Health care has yet to fully adopt a single terminology, but several are emerging as the primary contenders, including the Systematized Nomenclature...
of Medicine—Clinical Terms (SNOMED CT). It is a comprehensive clinical terminology, originally created by the College of American Pathologists (CAP), and distributed in the United States through the National Library of Medicine. Another terminology used to code laboratory and clinical observations is the Logical Observation Identifiers Names and Codes (LOINC).

Organized radiology has recognized the need for a standardized terminology focused on our daily work. There are terms and relationships that are unique to radiology not included in the above lexicons. Perhaps the best known radiology lexicon is that included as part of the Breast Imaging Reporting and Data System (BI-RADS), a quality assurance solution developed by the ACR. It prescribes how mammograms should be described and the terminology to be used for describing imaging features and the suspicion of malignancy. The Radiological Society of North America (RSNA) has sponsored a project to develop RadLex (12), a radiology terminology. It is an early effort and there are some gaps in its content. Terms not included within RadLex are continually collected and incorporated (13). This standardization of a vocabulary is a powerful enabler and we will see multiple examples here, even at this early stage, where the existence of a radiology terminology brings value (14–17).

### Image Metadata

An overarching informatics goal is to expose information in a computable format. Once in such a format, we can have systems perform tasks that are mundane or that we simply cannot perform as they are beyond human capability. Some of this information is available as “image metadata,” the “quantitative” and “semantic” information contained in an image that reflects its content. The quantitative information includes measurements of abnormalities, calculations within regions of interests, and numerical features extracted from images by a computer. Semantic information refers to the type of image, the imaging plane, and imaging features observed by the radiologist and the anatomic structures in which they are located. Imaging informatics tools may be used to build applications that use image metadata as the source data. For example, an application that automatically embeds the dose information from an imaging study into the radiology report would need to access the identifier of the study, the name and type of study (semantic data), and the dose information (quantitative data).

In the domain of radiology, there are evolving IT technologies—DICOM GSPS (gray-scale soft-copy presentation state), DICOM SR (structured report), and AIM
(annotation and image markup)—that represent efforts to capture and expose metadata. These three solutions represent a transition from predominantly displaying graphics and measurements (DICOM GSPS) to not only displaying but easily exposing these elements in a form that enables analytics, data mining, and application development (AIM). AIM is arguably the most information rich of the three, because it is built on a semantic model. The semantic model is the essence of AIM, specifying the types of image metadata contained in an image, the value types of the metadata, and relationships among those types. We will explore this further when considering the specifics of image interpretation and reporting.

IT INFRASTRUCTURE: THE UNDERPINNINGS OF RADIOLOGY OPERATIONS

Ordering, Scheduling, Exam Protocols, and Billing

These processes are hardly new, but they continue to evolve in the face of new technologies that can make them simpler and more efficient. IHE profiles are just one approach to better orchestrating the use of IT tools in these domains. There are parallel efforts. One such notable effort is that of the Society for Imaging Informatics in Medicine (SIIM). Its TRIP (Transforming the Radiological Interpretation Process) (18) initiative and, most recently, its offshoot SWIM (SIIM Workflow Initiative in Medicine) (19) are focused on addressing this problem. SIIM and other professional associations and societies are all trying to take existing and new IT technologies and apply them to the daily operational issues faced in radiology practice.

There is growing recognition that there should be some standardization of imaging procedures. For instance, a CT of the liver to exclude neoplasia is expected to include a particular mix of sequences. How might we automate the ordering, scheduling, and billing processes to achieve this expectation? Most imaging departments and offices start with a chargemaster, which includes an exam dictionary. A clinician orders from within an electronic medical record (EMR), which could use a radiology ordering module that includes a “standardized” exam dictionary. The RadLex Playbook is a project directed at developing an exam dictionary with an associated procedure-naming grammar, all based on the RadLex terminology. This dictionary can be directly tied to a chargemaster. The result should be some harmonization of exam directories and chargemasters across enterprises. The RadLex Playbook encompasses terms to describe the devices, imaging exams, and procedure steps performed in radiology.

Once we all agree on a standard exam dictionary, much efficiency follows. There would be consistency across all of health care as to how we name exams. The order can be passed to a scheduling system and then to a specific modality through a DICOM service, the “Modality Worklist.” This is commonly used to provide demographic information to a modality, eliminating the need for manual, error-prone input. In the near future, the modality would recognize the exam name and by convention would launch a preprogrammed protocol consisting of a standard set of imaging sequences. Consistent naming of exams would also make the entire billing process more straightforward, with the development of relatively standard chargemasters.

Radiology Order Entry Clinical Decision Support

Tools that assist the clinician in ordering the appropriate test have the potential to change the practice of medicine (20–24). When the clinician gets it right, the patient benefits! There is a tremendous amount of information available for clinicians to absorb and integrate into their medical practices. Radiology order entry clinical decision support (CDS) is quickly emerging in the era of the EMR as the IT solution to bring this information forward to the clinician when needed.

Safety, quality, and cost are the drivers that have prompted introduction of this technology. There has been extensive analysis of the inappropriate utilization of imaging services in the United States. It results in a significant economic burden (25–28) and, more importantly, exposes the patient and the population to unnecessary radiation (29–34), which is potentially harmful. An increased rate of neoplasia is a concern. Radiologists need to be the solution to this problem based on their professional expertise.

There are several causes of inappropriate utilization (25,26,35). Physician fear of malpractice litigation (defensive medicine), patient demand, financial incentives for inappropriate utilization, pressures to minimize an overall cost of an episode of care, and simply lack of knowledge (36) are all contributors. Repeat exams, initiated by clinicians but not necessarily recommended by the radiologist (37), and self-referral on the part of nonradiologists (38) are issues. Duplication of exams, because a recent result and set of images are not available is an additional factor (26).

Several pilot programs have demonstrated that CDS at the time of order entry can diminish inappropriate exams (32,39–44). A pilot study in Minnesota (32) demonstrated that imaging growth was curbed while simultaneously improving the rate of indicated examinations. An added benefit was that while radiology benefit manager (RBM) precertification required an average of 10 minutes of interaction, the CDS only required 10 seconds.

Making CDS Operational

CDS support requires a set of rules. The ACR Appropriateness Criteria (ACR-AC) (45) represent one such source. When a clinician enters an order, certain pieces of evidence are collected to justify the exam (Figs 1a and 1b). Some information is manually entered, often the “reason for exam.” Some of the information can be transparently collected from the EMR, including age, sex, problem list, etc. This information is electronically compared to the rule set and it is determined if the exam is appropriate. Some
applications return a yes/no answer; others provide a utility score (Figs 1c and 1d). If the exam is indicated, the order is accepted and sent from the EMR into an RIS for scheduling. If the score suggests that the exam is not ideal or is inappropriate, several actions can be taken. Alternative exams may be offered with their utility scores noted. The clinician may be given the option of proceeding with his or her original order, even if it has a low utility.

Throughout this process, information is collected in the background. A physician’s performance and ordering practices can be analyzed and compared to those of his or her peers or to established norms. This information can be used as part of an education and quality improvement process. Sometimes an outlier may be fully justified because of the nature of the practice. At other times, the ordering pattern may be truly inappropriate and education may be offered.

This system is directed at the ordering clinician, yet the radiologist is of central importance. It is our expertise, with consultation from other specialties, that should determine the rules and evolving guidelines. This is an evolution of our traditional role as consultants to the clinician.

**INTERPRETING THE IMAGE**

**Decision Support for the Radiologist**

When interpreting a set of images, a radiologist occasionally turns to a reference book or journal for further information before delivering the final report. Many have added the Internet as a source of information. A simple search engine, be it Google, Bing, or one of the many other generic services, often can quickly provide the needed information. There are dedicated radiology services available, including myRSNA (Fig 2a), a radiologist’s portal, and ARRS GoldMiner (Fig 2b) (46). Many of these search services are evolving to not only provide the radiologist with quick up-to-date information but will also credit the radiologist for the educational activity occurring simultaneously by awarding CME credit.
Figure 2. (continued)
Here, we see the value of a lexicon such as RadLex in searching. Free text queries have been mapped to RadLex terms. This in effect helps to refine the user’s search and focus the search results on the true subject of interest (14).

Paid knowledge services are also growing. A dictation/transcription vendor has incorporated a semiautomatic search wizard (Fig 2c) into the dictation interface so that the radiologist in the midst of reporting can quickly access a rich array of information services. One can expect to see this kind of “point of service” solution appearing in a growing number of applications that are part of the reporting cycle.

The goal is to make the correct knowledge available as easily and efficiently as possible. Tools currently in development are “watching” the radiology dictation in real-time and using natural language processing (NLP) to identify key trigger words, search Internet resources in the background, and bring back relevant information transparently.

**Computer-Assisted Diagnosis**

Postprocessing of our image data is now routine. Cross-sectional imaging has leveraged multiplanar and three-dimensional technology to better depict and assess pathology (47). Advances in the processing power available at the desktop, advances in graphics processors, and algorithms have all contributed to making these tools affordable.

Another form of postprocessing is computer-assisted diagnosis (CAD). These applications attempt to directly identify pathology. The greatest availability is for breast imaging (47,48), but applications are quickly emerging for the analysis of lesions in a variety of organs (49,50). Figure 3 includes images from a lung CT nodule CAD. It identifies potential lung nodules, shows them in a three-dimensional rendering of the chest (Fig 3a), exports a series of axial images containing the identified nodules to PACS (Fig 3b), and provides detailed information regarding the dimensions and density of the nodules. If sequential exams are available, this system will calculate temporal changes and doubling times (Fig 3c).

These solutions are not perfect. Many suffer from a high number of false-positives. Changing parameters for sensitivity will alter the specificity. However, there is a growing literature that suggests these tools, used as a second read, increase the accuracy of the radiologist. The radiologist is the owner of the final report. These systems are tools that require the
knowledge and judgment of the radiologist in understanding how to use the information provided.

**A New Level of Decision Support**

Probably everyone is aware of IBM’s Watson, which IBM represents as a new model of CDS. IBM is working to leverage this technology in health care (51). Existing systems perform a key word search. The user selects and enters keywords, which are then searched by an engine that is looking for those words, without context. Watson may improve on this scenario. It has a sophisticated NLP engine that removes the task of selecting the key words, speeding the overall process. Watson takes the keywords it has chosen, in the context they are presented, and generates hypotheses from an extensive knowledge base. It then evaluates each hypothesis by searching for more supporting evidence. The ability to ingest enormous amounts of free text information...
about a given patient and mine exhaustive knowledge resources may lead to a level of decision support barely entertained just a few years ago. The time-consuming manual processes that we perform today may be replaced by systems that almost instantaneously direct our thinking to a focused differential diagnoses with supporting documentation. IBM is establishing research relationships with academic health care sites to tailor its proposed solution to the health care environment.

NEW PARADIGMS IN REPORTING

The New Narrative Report

The radiology report is our primary vehicle for communicating results. Expectations for the information elements that comprise a report are changing (52). While the foremost mission of the report has been to provide a diagnosis to the clinician, there has been an increasing demand to expose other pieces of information within a report for quality and financial purposes. Payers wish to know the reason for exam, as do the radiologists and clinicians. Historically, the provider could express this in a somewhat whimsical form, yet successfully communicate the desired intent of the exam. Payers have demanded a more regimented indication. Other kinds of information that are expected today include contrast type and volume and radiation exposure. Notification of a critical alert should be documented in the report. Clinicians are looking for particular positive and negative observations in the assessment of potential disease processes.

The idiosyncratic tomes provided in the past are disappearing and being replaced with “structured” reports (53) with predefined, expected elements. The report may be based on a template. They may be populated by the radiologist, but information of interest may already be present electronically and can automatically populate the report. The basic elements that should comprise a report have been identified in the ACR’s Practice Guideline for Communication (54).

Structured reports appeared many years ago, but the tool sets available were limiting. Today there are more robust applications available, primarily voice recognition transcription systems. These offerings are now pervasive, with recognition engines that can approach 99% accuracy or better for some users. They often include macros, that are templates that can be triggered with a word or automatically populated by recognition of an exam type. No matter the mechanism, they provide the means to “structure” a report. Structured fields may be mandatory or optional; they may be filled in verbally or automatically from other systems. Not all this information needs to be displayed for all readers of a report. The presentation state of the report can vary depending on the individual reading the report (52), exposing only the information that is valuable to the end-user, but always having the potential to display the complete information set. A provider view of the report might be different than that provided to the patient or a billing office.

The structured report provides the opportunity to consistently include and hence discover, with IT data mining tools, specified data elements. We are enabling our quality assurance and research missions while simultaneously improving patient care by ensuring that the right data elements are always present. Standardized ways of reporting and communicating “critical results” can be launched by including “triggers” in the report. These triggers can spawn communication applications that ensure notification has taken place and record the receipt of the message by the clinician (53,55–58).

The RSNA has established a Radiology Reporting Initiative, a committee that includes domain experts to develop templates. This committee will promote best practices in reporting, including fostering structured reports when appropriate (53).

As much as structured reports can facilitate quality and research initiatives, we should not lose sight of innovative opportunities that new technologies offer. Although not routine, we now have the capability to include significant images in the report, with image annotations. NLP applications, such as Watson and Leximer (58), are emerging, which can derive meaning from free text (51,52,58). In the future, a combination of structure and free text mined by NLP tools will enable automated actions triggered by text.

Reporting the Metadata: AIM

In addition to the radiology report, a radiologist commonly indicates the location of a lesion by drawing an arrow or using the measurement tool (quantitative data) and dictates a statement in the report to describe the lesion (semantic data). Recorded as graphical overlays and free text in the radiology report, these data are not easily accessible to computer applications.

AIM was developed to address this issue (59). It provides (1) a “semantic model” of image markups and annotations, (2) a syntax for capturing, storing, and sharing image metadata, and (3) tools for serializing the image metadata to other formats such as DICOM-SR and HL7-CDA (60). The types of image metadata encoded by AIM include imaging observations, anatomy, disease, and radiologist inferences (61). AIM distinguishes between image annotation and markup (Fig 4a). Image annotations are descriptive information, generated by humans or machines, directly related to the content of a referenced image. Image markup refers to graphical symbols that are associated with an image and its annotations. Accordingly, all the key image metadata content about an image is in the annotation; the markup is simply a graphical presentation of some of annotation image metadata.

AIM is complementary to DICOM-SR with respect to providing a syntax for storing and exchanging image metadata. DICOM-SR, however lacks a semantic model of the image metadata, which is the major reason AIM was developed.

AIM makes the semantic contents of images explicit and accessible to machines, thereby providing a framework that can be leveraged by a variety of emerging applications,
“Patient: Mary Jane”
“CECT exam on 11/4/2011”
“Axial 3mm slices through the abdomen”
“There is a hypodense mass with fuzzy margins measuring 4.5 x 3.5 cm in the right lobe of the liver.”

Figure 4. AIM (annotation and image markup) is a new tool to expose image metadata and make it accessible for a variety of applications. (a) Image metadata. This shows an example image and excerpts from the radiology report. The graphical symbols drawn by the radiologist on the image (“markups” indicating measurements of a lesion—quantitative data) and the statements in the report about the patient, type of exam, technique, date, imaging observations, and anatomic localization (semantic data) collectively comprise the image metadata (“annotation”). These image metadata, if stored in a standardized, machine-accessible format, greatly enable many computer applications to help radiologists in their daily work. (b) ePAD-rich Web client. The ePAD application provides a platform-independent and thin client implementation of an AIM-compliant image viewing workstation. Information about lesions that are marked up and reported by radiologists is captured and stored in AIM XML (or DICOM-SR [digital imaging and communications in medicine—structured report]). User-definable templates capture semantic information about lesions, such as shown in this case for oncology reporting, the type of lesion (target), anatomic location (liver), and type of imaging exam (baseline evaluation). (c) Radiology image information summarization application leveraging the utility of AIM-encoded image metadata. A cancer lesion-tracking application has queried AIM annotations created on different imaging studies (in this case, from three studies on April 3, June 6, and August 6, 2008). The application automatically calculates the sum of each target lesion measured on each imaging study date and summarizes the results in a table (left) and graph (right). Using metadata from the AIM annotations, the application also displays alternative response measures such as maximum length (red line) or cross-sectional area (black line) of the measured lesions. (Color version of figure is available online).

including image search, content-based image retrieval, just-in-time knowledge delivery, imaging information summarization, and decision support. AIM enables systems to search for information that was either hidden or not directly linked to the relevant images. In clinical practice AIM will make it possible to directly retrieve prior images for comparison, rather than simply prior studies. Today, reviewing the prior studies, particularly to identify lesions being followed for assessing cancer response, slows the workflow (62). AIM-compliant image annotation tools that streamline the summarization and review of prior imaging studies are being developed (63). All the data needed by applications to process from images are available in a compact, explicit, and interoperable manner.

A number of image-viewing workstations adopt AIM (64–66). These tools provide an annotation palette with drop-down boxes and text fields the user accesses to record semantic information about the images (Fig 4b). They save
the image metadata in AIM format. The latter can be transformed into DICOM-SR using the AIM toolkit, or users can store AIM in a relational database, enabling access for a variety of applications such as lesion tracking and reporting (65,67) (Fig 4c). The process by which radiologists view images and create AIM annotations is similar to the current process by which radiologists perform this task—by drawing or notating directly on images.

**RADIATION IN THE CLOUD**

**Image and Report Exchange**

We have entered an era where patients are extremely mobile and their longitudinal record is often comprised of documentation dispersed across numerous sites. Health care data exchange, including imaging (68–70), is fundamental to maintaining the integrity of the patient’s longitudinal medical record. When presented with an abnormal exam, the first question asked by a radiologist is whether there is an historical exam available for comparison. Unfortunately, historical exams are often difficult to obtain.

Lack of availability of an historical exam is a contributor to inappropriate utilization through redundant imaging. Easy accessibility to historical exams on either CD or via the Internet can diminish this phenomena (71,72), CDs, representing a significant improvement beyond sharing on film, remain fraught with problems (69,70), ranging from damaged discs to proprietary formats not readable universally. Last, one needs to have the physical media on their person.

We share many things on the Internet, with music, photos, and videos being among the most common. We shop there, and it is not unusual to perform banking activities. Why not extend such service to health care, enabling your medical record to be available anytime and anywhere? We have seen the beginning of an explosion of Internet-based health care information exchange. This has included regional health information exchanges (HIEs), personal health records (PHRs), peer-to-peer sharing, vendor-based sharing (sharing limited to the customers of a single vendor), and a multitude of variants. The federal government is fostering exchange through the National Health Information Network (NHIN) as well as several National Institutes of Health (NIH)-sponsored pilots (73–75). An early federally sponsored foray into sharing is a project known as NHIN Direct, which promotes information exchange through a secure email mechanism.

There have been successes and failures. Challenges include establishing a firm economic basis for this service. Economic models are being tested, including costs underwritten by government, patients, providers, and payers. Most agree that such exchange should improve quality and is likely to drive down overall costs. The HITECH Meaningful Use program includes such exchange and clearly sees it as one of the most important long-term outcomes.

Imaging has been relegated to a position of lower priority challenged by the bandwidth required to move images across the Internet. Image data sets are exponentially larger than the text and discrete lab information that comprises most of health care data. The storage and transmission requirements over consumer and small business Internet services have been gating elements. This is all quickly changing as technology advances and costs diminish.

Internet-based image exchange has arrived in a spectrum of “cloud services” including research-sponsored trials and some innovative private vendor services.

Internet image exchange commenced a few years ago when enterprises extended image and report viewing outside their local four walls. PACS viewers, often Web based, would connect from the external offices of clinicians to a PACS, often through a “virtual private network (VPN)” connection. The key is that the individual with the external connection is usually well known to the enterprise.

The next generation of connectivity has been targeted at large extended enterprises and/or a few independent enterprises with legal arrangements to share data. A growing number of businesses provide proprietary exchange solutions. They use the Internet to permit the linked partners to share information. They provide patient identification services and Medical Record Number (MRN) reconciliation, record locator services, and connect disparate systems so that data originating at one site can be seen at another.

But this is not full exchange. There are limiting boundaries present. Full transparent interoperability occurs when anyone with proper patient authorization, provider or other, no matter their location or employer, can view the data. There are several models. The first is the HIE. Many enterprises on a regional level or beyond agree to share information that passes through a central repository. Safeguards are put into place to ensure that patients have consented for such exchange. IHE provides the Cross Enterprise Document Sharing (XDS) (76) profile, a well-described technical and workflow solution to support such exchange. Documents arise at a “source” and are “consumed” at the other end of the chain. In the middle are a set of services to (a) identify the patient through reconciliation of his or her demographic information as the patient moves through the system, (b) register and store data in a common repository and provide record locator services, (c) confirm patient consent, and (d) send the data to a properly authenticated recipient. Audit trails are maintained. HIEs built on solutions other than IHE usually provide a similar set of services. An advantage of IHE is that these are standards-based solutions and thus nonproprietary. For imaging, IHE describes XDS-I (77) (Fig 5), which addresses the large bandwidth issues that accompany imaging.

Another solution is putting control of sharing data, including images, into the hands of the patient, through a PHR. Several early proprietary image-enabled PHRs have arisen, but attaining a critical mass of patients has been limited by the proprietary nature of those solutions. The RSNA, along with vendor partners, launched a PHR service, the
RSNA Image Share (73), under NIH sponsorship using the XDS-I profile. The goal is to leverage standards and enable the critical mass to be attained. The same standards based infrastructure can enable other forms of sharing. This project is live and enrolling patients.

Another solution is peer to peer networking, usually between providers. In this scenario, physicians take ownership of their patients’ images and can share the images with other physicians. All these methods represent early incarnations, constantly undergoing modification in their technology and business models in parallel to government incentives to promote sharing. The ultimate goal is to make the patient’s image and report available anywhere and anytime when proper consent and authentication are provided.

**CAD Everywhere**

We described how the current state of postprocessing will advance. Postprocessing workstations, often at high cost, have been available for many years, first introduced as standalone workstations. There has been a trend to move to thin-client and/or Web-based applications. In this configuration, a “lite” application or Web link resides on a local workstation that connects to a central server, possibly in the “cloud” where intensive processing takes place. The application can easily be distributed to numerous distributed workstations. Purchasers acquire these services through concurrent user licenses. An end-user no longer needs to be at a single location to obtain a postprocessing result. Location is almost meaningless; availability is ubiquitous. Cost and implementation models are drastically modified.

**MISCELLANEOUS FUNCTIONS IN A RADIOLOGY PRACTICE**

**Quality**

We are increasingly facing a regulatory environment where performance is measured and meeting certain thresholds is a requirement for practice. Next, we cite several scenarios where IT tools are providing solutions that enhance the delivery of and measurement of quality in radiology practice.

Image quality is already being measured, often breast imaging and CT. In addition to inspection by local municipalities, the ACR provides certification of these modalities. Currently, images are shipped on film and/or CD to demonstrate that a practice meets quality measures. This process can be complex and time consuming. It can be simplified by implementing Internet-based solutions that aggregate the data from a practice and export it to the regulatory authority.

Limiting the radiation exposure of the individual patient and the overall population has become one of the highest priorities of our profession. Best practices are being actively promulgated through efforts such as “Image Gently.” In parallel, there are evolving IT solutions that will contribute to this effort. The ability to measure radiation exposure is cardinal to addressing this issue. The IHE Radiation Exposure Monitoring (REM) profile (Fig 6) describes the steps and associated standards required to accomplish this task. Several vendors have introduced products that follow this profile, aggregate the exposure data from a variety of modalities, and provide analytics so that a radiology department or imaging center can easily monitor their performance. Some solutions permit an extremely detailed analysis. Performance of individual
devices, protocols, and the personnel operating the equipment can all be measured. The practices of each individual radiologist can also be analyzed.

The ACR Dose Index Registry (DIR) (78,79) is a project that has leveraged informatics tools since its inception to make the regulatory process easier. In its first incarnation, CT scanners provide the dosimetry information, exam by exam, to a local aggregation point (computer). A software application collects information, deidentifies it with regard to patients, specifies what exams were done, and at which practice. It is exported to the ACR. The ACR provides back an analysis including how your practice performs compared to others. A number of vendors can also provide this data to the ACR and provide even more detailed analytics, as described earlier, for an individual site.

Figure 6. (a) Integrating the Healthcare Enterprise (IHE) includes a Radiation Exposure Monitoring (REM) profile. It describes how to collect dose information from a modality, and store it locally. It also describes a set of transactions to share it with an external registry. (b) A graphical representation demonstrates the flow of the dosimetry information from modalities to a local archive, an analytics application, and ultimately a national registry. (Color version of figure is available online).
The DIR is another example of where the availability of a standardized terminology can enhance an application. Earlier in this report, we noted that many “brain CTs” were identified by a large variety of names. The ACR has developed a mapping tool permitting a site to map its exam dictionary to the RadLex Playbook ID, harmonizing the exams conducted in different offices under different names.

Another example of a quality improvement program, built to leverage informatics tools, is RADPEER (80), the ACR program to encourage peer review. There are a variety of means of entering the peer review score, including manual data entry. Several vendor applications foster peer review during the course of daily interpretation, collecting the necessary data electronically. The scores are aggregated by the application and electronically submitted to the ACR.

Residents and residency programs are being measured by metrics identifying what types of exams have been seen and reported. The Accreditation Council for Graduate Medical Education accreditation programs require reporting this data. Many sites are aggregating that data by mining their RIS or reporting systems. Vendors are delivering new products to enable such data mining.

These early efforts are laying down the fundamental methodology to enable the collection of all kinds of performance indicators from data in our radiology IT systems, permitting measurement, comparison, feedback and remedy when problems are identified. In parallel, quality assurance officers are exploring ways to make this educational rather than punitive.

Research

Comparative Effectiveness Research. Our profession has an ongoing research mission. How should our modalities be employed in the management and treatment of patients; how do we assess clinical impact? Comparative effectiveness research (CER) has emerged as the dominant approach, going forward. When possible, clinical trials should compare proposed imaging solutions, to others, and even to managing the patient without imaging.

The American Recovery and Reinvestment Act of 2009 (ARRA) substantially extended federal support for CER and created the Federal Coordinating Council for Comparative Effectiveness Research (FCC) (81), which has issued a report laying out a process for promoting CER (81,82). The report provides this definition of CER: “Comparative effectiveness research is the conduct and synthesis of research comparing the benefits and harms of different interventions and strategies to prevent, diagnose, treat and monitor health conditions in “real world” settings.” Currently, the minority of radiology research is directly comparative in nature. In the CER-FCC report, imaging was cited as a domain where there is potential to have high impact (83).

The ACR has a formal mechanism to determine the utility of imaging exams to diagnose disease, by evaluating the existing evidence based studies, comparing the modalities evaluated, and synthesizing this information into a utility index, the ACR–AC. The initial methodology of establishing the ACR–AC uses the RAND/UCLA Appropriateness Method (43, 84–86), based on both evidence and consensus. The ACR criteria provide a comparative utility score for relevant modalities for varied clinical indications. There is an explanation of the rationale with documentation of the relevant literature. For some of the ACR–AC categories, there is an “evidence-table” provided in which the ACR identifies studies that were comparative, though the comparison is not always between imaging studies, and sometimes reflects the comparison of a single modality to clinical or surgical assessment. There are few controlled studies in the literature related to the clinical impact of the various modalities in many diseases, so CER evidence is generally lacking. The ACR–AC is a hybrid, with primary CER probably represented in only a minority of the criteria.

The combination of decision support tools such as the ACR–AC, along with data mining tools that can extract the results and outcomes from a combination of radiology reports and the EMR, can create a closed cycle directing a patient into particular imaging studies and determining which of those studies alters patient outcome, for better or worse. Ideally, prospectively designed randomized controlled studies comparing imaging strategies can be implemented with the data mining tools in place to better understand outcome. Additional methodologies can be considered when prospective studies are not feasible. Using the tools discussed, we can begin to retrospectively examine large volumes of data (87), which was not possible in the past, and compare the performance of modalities. While less ideal than the carefully constructed prospective trials, the aggregation of large volumes of patients opens the door to statistical analyses that may provide reasonable comparative analysis.

Research Recruitment

The recruitment and identification of appropriate patients for clinical trials are often challenging. Data-mining tools running in the EMR or in the enterprise’s data warehouse now offer a solution. Investigators can run real-time algorithms in their EMR to look for trigger events that suggest a patient might be a candidate to participate in a clinical trial. These tools usually provide notification to the provider, who can then choose to inform the patient of a trial.

As clinical trials are conducted, there is a desire to recruit patients from a broader number of sites, rather than just academic campuses. The Internet provides an opportunity to efficiently collect data, deidentify it at the local site, and almost instantaneously provide it to a central site. The ACR Triad server has been repeatedly used to accomplish this in ACR Imaging Network (ACRIN) trials. The RSNA Clinical
Trial Processor (CTP) is another such solution. There are also proprietary solutions. Patients may enter trials that at times leverage technology far from home, without the cost of travel. Some advances are based on new technologies not available in every local environment. Data sets obtained on local instrumentation can be exported to sophisticated postprocessing environments in the "cloud" and results returned to the local environment and study center. This may be an extremely effective mechanism of efficient resource utilization.

**Big Data**

Perhaps the most exciting frontier is that of “big data,” involving genomics and proteomics (88,89). Molecular data need to be analyzed in the context of phenotypic data. This requires high-performance computing solutions. These computing environments are searching for relationships between these data elements to understand the etiology and predictors of disease. Medicine may well switch from a reactive practice to a proactive preventative paradigm.
as these investigations mature. Certainly imaging will play a major role as systems supporting analysis of big data emerge, and standards in terminology and image metadata described earlier will serve a major role in enabling these systems.

**Education**

We educate technologists, physicians, nurses, and administrators, as well as the general public. Textbooks and didactic lectures have been our core educational materials. The domain of education has evolved its own informatics tools to provide innovative ways for individuals to learn. The entire field of education is undergoing a revolution related to network-based tools, the ability to interact through commonly available devices such as smartphones, and to marry learning to one's daily work. These include learning management systems (91), which are tools to organize e-learning, a process to foster learning through interactive, engaging modules free of time and place restrictions.

The informatics tools we have described here expose radiology and medical information. Information is discoverable and can be repurposed in the e-learning environment. The Shareable Content Object Reference Model (SCORM) is a standard, used in many industries, for the management of educational content that enables the development of e-learning applications (90,91). There is an initiative, “SCORM for Healthcare,” that is promoted by the MedBiquitous Consortium. Efforts such as the RSNA RadSCOPE (Radiology Shareable Content for Online Presentation and Education) leverage SCORM to provide content for the development of educational services.

Radiology educators are exploring new ways of bringing information to the radiologist, especially in the context of one’s daily work of interpreting exams. Education applications nurture just-in-time learning, monitor one’s use of such systems, and award educational credits. Newer technologies might monitor one’s performance and bring forward educational resources when one’s performance falls below a certain threshold.

**CONCLUSIONS**

Radiology informatics may be best understood as a set of tools that enables a continual cycle of enhancing exam workflow, with quality controls, reporting, and research (Fig 7). Some informatics tools may seem mundane, others innovative, but together there is a synergy that permits our profession to remain fresh and exciting, providing patients with earlier and better care, often at a diminished cost.

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