A Revolution In Radiology: PACS* 101 (Part 1)

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*Picture Archiving and Communication System

Ask the average physician to cite the most revolutionary advance in radiology during his or her lifetime, and most will mention innovations like CT scanning, MRI, or interventional radiology. But they would overlook one of the most unheralded yet fundamental innovations of all: how we process, store, and access images and their descriptions.

In the dark ages of imaging, a mere 10 years ago, life was very different; imaging studies were performed and recorded on film. Films were processed in a darkroom or the equivalent; given to the radiologist who dictated a report; then stuffed into jackets for storage. After the reports were typed and signed, couriers took them to the floors or they were put into mailing envelopes. A clinician who wanted to see the images made a trip to the radiology department, hoping and praying the films could be found in a timely fashion. Since there were often many people trying to see the same studies, and many places where they could hide (radiologists' offices, surgeons' car trunks, etc.) the process was often intensely frustrating and decisions about patient care were frequently delayed.

The studies were much different as well. CT scanners were much slower and the images were less detailed. An average CT study contained fewer than 100 images, and was typically filmed on 3-5 sheets of 14" x 17" film. With 20 images per film (usually arrayed 4X5), banks of view boxes were required to display the current and prior studies. The viewer scrutinized page after page looking for important findings, and compared the images with prior studies, if available. If the technologist didn't measure a finding or optimize the view of certain pathology, it was either missed, or the study was sent back for additional processing, further delaying access to the images and the report.

It is hard to believe how recently the above scenario was the norm, yet all but the youngest of us trained and practiced in that environment. Today, everyone can access the study as soon as it's completed, and the films are almost never missing. Of course not all problems have been solved. As the system has become ever more technology-driven, familiar gremlins that plague electronic devices have intruded, with effects amplified by the size and complexity of the systems involved.

THE IMAGING DEVICE

Everything starts at the device that makes the image. For plain "films," mammograms, and fluoroscopy studies, film has been replaced by computed radiography (CR) or digital radiography (DR). With CR, a device that looks like a film cassette can be placed in a standard X-ray room, the picture taken and recorded on a special plate, and the plate then "read" by a device called a plate reader. The resultant image data can then be viewed on a computer screen. DR eliminates the cassette entirely; the X-ray beam strikes a built in detector and the digital data transfer directly for reading. CR allows the use of older X-ray rooms and is cheaper. DR requires new X-ray rooms, but is faster and more robust. Mammography has skipped the CR step and gone directly to DR.

The other major imaging modalities, CT, ultrasound (US), MR, and nuclear medicine (NM) all acquire their data in digital format, that is to say, they already generate the image as individual picture elements or pixels, each of which is assigned a shade of gray to create the final image. The picture you see is simply the matrix of these individual pixels aligned in columns and rows to make an image. The smaller the pixels, the better the detail, but the longer it takes to make the image. Each modality is limited in the level of spatial resolution it can achieve based on the physical limitations of that particular device.

As the technologist acquires the images, they must be attributed to the right patient. In the past, the technologist received a paper request for the study, and typed all the information into the imaging device (or worse, wrote it on a little card that was exposed with the X-ray). Today, the imaging study is ordered in the radiology information system (RIS) by the unit clerk or the physician's office staff, the patient's demographic information is transferred from the hospital information system (HIS), and the resultant information is passed directly to the imaging device in the form of a work list. The technologist selects the patient from the list, and all of the important information

about that patient is attached to the images, with much less chance of error. No more misspelled names, no more wrong medical record numbers. The major sources of error now lie at the beginning of the process, with the transcription of the provider's written request into the system. This problem will soon be addressed in the electronic medical record through computerized physician order entry (CPOE), which eliminates the middleman and allows physicians and other licensed providers to order directly from drop-down menus, and which can ultimately provide decision support to make sure that appropriate studies are ordered. This will help reduces healthcare costs considerably, as duplicate or unnecessary exams can be caught before they are ordered or performed.

PACS

After the images are obtained, a system is needed that displays and stores this information, and allows its transfer to wherever it needs to be viewed, be it the radiologists' reading area, the ICU bedside, or the ordering physician's office. This system's rather awkward name is Picture Archiving and Communication System, or, more euphoniously, PACS. This technology, first implemented in the 1990s, has matured over the past 10 years to provide robust solutions for the management of imaging data.

The image or images, acquired on a variety of devices made by several vendors, must be brought into the system for review and storage. The good news is that very early in the development of PACS, a standard was developed, called DICOM, which was supposed to permit any vendor's device to send images to any PACS system with consistent display parameters and opportunities for post-processing of the images. Alas, DICOM is a "standard" in the same way that Taco Bell is a Mexican restaurant. Although the situation would be even worse without any standard, many vendors, particularly those that sold both imaging equipment and PACS systems, created their own "flavors" of DICOM to increase the likelihood that hospitals and offices would buy all of their equipment from a single vendor. The result has been that every institution with equipment from various manufacturers (which is almost all healthcare organizations) has had to struggle and compromise to get the systems to work well. The situation has improved gradually over the past decade, as purchasers have increasingly shunned sellers who play these games, but it remains true that not all DICOM images are created equal, and that PACS systems must employ a variety of tricks, workarounds, and inconveniences to allow display of all the images made by an individual hospital or system, or

imported from another institution. We are still some distance away from a totally portable medical record.

IMAGE DISPLAY

As anyone paying attention to healthcare knows, the last 2 decades have seen rapid growth in the use of diagnostic imaging, and the development of many new imaging modalities. While the basic chest X-ray has remained a 2-view exam, and the basic screening mammogram is 4 images, there has been an explosion of imaging data, particularly in the realm of CT and MR. As mentioned previously, an old CT exam might at most have involved 100 images; today a typical CT may involve 300–500 individual pictures, and many CT angiograms run well over 1000 images. Similarly, most MR's have several hundred images, and PET-CT studies have more than 1000 images. It is no longer feasible to display these images as individual pictures in a grid on a screen. Instead, the images are "stacked" and can be viewed by looking at one screen, and scrolling through the data, analogous to the old flip books that told a little story in motion by flipping through pages very rapidly, each picture varying only slightly from the prior one, but creating the sense of smooth motion.

In addition, the data that comprise the images can be manipulated to view them in multiple planes besides the traditional axial plane, such as coronal, sagittal, or oblique planes of section. Different windows and levels can be displayed to optimize the study of bone, lung, or soft tissue. Some PACS systems, or special add-on programs, will use the data to generate a 3-D image, or accentuate certain features such as blood vessels or airways. Measurements of distance, angle, or density can be calculated, and key findings can be circled and saved for the next viewer. Images can be made lighter or darker, or contrast can be altered to optimize the viewing of certain abnormalities.

The viewer can also access prior studies for comparison. Most PACS systems use a tool called prefetching; when a study is ordered, the PACS goes automatically to the image archive and loads older similar exams on the same patient into short-term memory, where they can be accessed almost instantly as needed. In addition, current and prior reports, as well as notes from the technologist regarding history, contrast dose, and patient factors are transmitted to the radiologist to aid in interpretation. In the new world of the electronic medical record (EMR), the PACS can be linked to the EMR and the entire patient record made available to the interpreting radiologist at the click of the mouse, This can add greater value to the radiologist's report,

as he or she can integrate the imaging findings with the entire clinical picture, and not merely the few crumbs of history provided on the typical requisition.

IMAGE STORAGE

With the aforementioned explosion in imaging, involving not only the number of studies but also the amount of data contained in each exam, an entire industry has grown up around archiving these data. As with film, the law requires digital images of adults to be saved for at least 7 years, with even stricter requirements for pediatric images and mammograms. The development of PACS has closely paralleled the constant increase in speed and decrease in cost of storing digital data. Today, most PACS systems rely on a combination of short-term storage, usually on some sort of spinning disc or discs (relatively expensive), and longer-term storage on optical media or banks of hard drives (less expensive). With the former, recent and prefetched studies can be accessed within a second or two, while retrieving a prior exam from the deeper archive may take longer, perhaps 30 seconds to several minutes. This difference seems small, but in a busy radiology department, where one radiologist may be reading 100 or more exams in a day, the difference is huge. These systems can be, and need to be, very large - able to handle not only present needs, but also projected future needs. Ideally, they should also be vendor-neutral, storing the data so that a change in imaging equipment or PACS vendor does not render images unavailable, or in need of "translation," a process that seriously slows retrieval. At Lancaster General, we generate about 2.5 terabytes of data each month. For comparison, a very large home PC drive is one terabyte.

IMAGE COMMUNICATION

Finally, the completed study and the report must be available to everyone who needs access to it—those caring directly for the patient, while maintaining a high level of security so that personal health information is protected.

- Within an institution, computers must be available to allow providers to view images at bedside or on the unit.
- Physician offices need Internet access to view these images.
- Some specialty users, such as orthopedic surgeons and neurosurgeons, need access to sophisticated post-processing tools to make surgical decisions; they must have compatible viewers to permit these functions.
- If the patient seeks care elsewhere, the images need to be placed on a CD or DVD, or sent securely over the Internet, and must be in a format that can be easily viewed by the end-user, even if they have a different PACS, which they often do.

Moreover, an infrastructure of support staff must be developed and maintained to help with these processes—particularly for the less computer-savvy among us—and to address computer crashes, network malfunctions, etc. All of this represents the ideal, and though it is getting closer, it is still not here for everyone all the time.

CONCLUSION

In those dark ages of a decade ago, a 90% 24-hour turnaround time between the study being completed and the images and reports being available was considered admirable. Today, routine studies are expected in 4–8 hours, while Emergency Department turnaround times are measured in minutes, if not seconds. Inpatient reports are expected in an hour or two at most, in order to expedite the care of the patient and to shorten hospital stays. At Lancaster General, one-third of all studies requested are ordered "Stat," with the expectation of very rapid performance and interpretation. None of this would be possible without the death of film and the advent of PACS. Today's PACS systems provide extremely sophisticated solutions to the demand for instant results. Even more valuable tools lie in the near future, as mobile computing devices and ever-more powerful hardware and software allow better management and utilization of the wealth of available information.

Part 2 will discuss some of the newer tools available now and on the horizon, as well as a bit about the "darker" side of the digital revolution.

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