Imaging Informatics: Waking Up to 50 Years of Progress

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Imagine a radiologist who, like Rip van Winkle, falls into a deep slumber in 1971 and wakes up 50 years later. Despite the many amazing developments in MRI, CT, and other modalities, our radiologist might be most astounded by how radiology itself has changed during those intervening years, thanks to advances in imaging informatics.

Wiping the sleep from his eyes, the good doctor would see:

1. Universal and instant access to images using computer workstations.
2. Upwards of 50,000 images being reviewed each day, rather than just a few hundred.
3. Radiologists—not transcriptionists—creating their own reports using speech recognition, with turnaround times measured in minutes instead of days.
4. High-resolution images immediately available on monitors with automated hanging protocols, rather than being hung manually on a film alternator by the film librarian.
5. Images optimized for contrast and brightness digitally rather than with a mounted light bulb and floor pedal.
6. "Wet Reads" for the emergency department appearing digitally just seconds after images are obtained, rather than being grabbed while actually still wet from being hand dipped into processing solution.
7. Artificial intelligence (AI) that swiftly detects and diagnoses cancer and microcalcifications on mammograms and other studies—in the place of a second, human, reader.
8. Nearly instantaneous results for information by searching the Internet ("*the inter-what?*") rather than by pulling old textbooks off reading room shelves.

There have been many critical milestones along that journey of imaging informatics. One of the first was the development, in 1982, of the radiology information system. The Radiology Information System Consortium (progenitor of the Society for Imaging Informatics in Medicine) teamed up with the Digital Equipment Corporation to create DECrad,[1] a breakthrough in the transition from hardcopy reports and manual billing to the digital reports and billing of the digital era.

Filmless Arrives, in Bumps and Starts

Once imaging reports were digital, it became clear that the next goal was to achieve filmless imaging. Several hurdles, however, delayed the arrival of that advance for more than 10 years. Indeed, to create a truly "filmless" department, x-ray film itself had to be digitized. While it is true that Fuji released a digital computed radiography system using digital detectors in 1983, ironically the company only agreed to print these images to film. It took almost a decade to convince them to send the images to a digital archive instead.

Another major challenge to filmless imaging was the "Tower of Babel" created by each imaging vendor's own, proprietary way of

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The author reading images and dictating findings at a modern-day digital workstation.

representing, transmitting, and storing digital images. The National Electrical Manufacturers Association and the American College of Radiology (ACR) created a DICOM committee in 1983, and by 1990 a second version of the standard was being tested at Georgetown University.[2] This standard, which enabled a single archive to store and retrieve images from multiple vendors and modalities, led to the creation of specifications for, and purchase of, a picture archiving and communication system (PACS) by the US Army's Medical Diagnostic Imaging Support program. Owing to a lack of an electronic medical record system (EMR) interface and other factors, however, the Department of Defense didn't make the transition to fully filmless operation until years later.

The DICOM standard typically required a third-party vendor for successful implementation of PACS through most of the 1990s. But that began to change in 1998, when the RSNA's "Integrating the Healthcare Enterprise" initiative created consensus among vendors on configuring and testing DICOM for real-world PACS implementations, setting the stage for "plug and play" PACS.[3]

First Filmless Hospital Brings a Host of Challenges

In 1993, the newly constructed Baltimore VA Medical Center opened its doors as the world's first filmless hospital, taking advantage of a robust interface to the VA's VISTA EMR system, representing a major paradigm shift to 100-percent digital operation. This initially raised legal questions about "film storage" in a filmless department, given the mandate to store film for 5 years, and the review of images such as chest radiographs on monitors that had inherently much lower spatial resolution than film.

Among other challenges wrought by the debut of a filmless facility were lower monitor brightness and new ergonomics issues, especially related to lighting and the use of a computer mouse. Pundits feared that universal access to radiology images by emergency room physicians and other clinicians might portend the "end of radiology." In addition, although computer workstations and monitors were moderately expensive, image storage was prohibitively expensive; a one-terabyte optical jukebox archive cost about $800,000—some 20,000 times the price of an off-the-shelf, one-terabyte drive today.

Despite these obstacles, for the first time in medical history, images could be made available anywhere, any time to all authorized healthcare providers. They could be enhanced at the workstation (window, level, zoom), annotated digitally, and measured on-screen. MRI and CT images could now be routinely reviewed in stack or cine mode, permitting rapid review of cross-sectional slices. So-called "advanced visualization" systems permitted multi-planar and three-dimensional images to be reviewed at a single workstation, replacing multiple expensive, dedicated CT and MRI workstations that did the same thing. Along with stack mode, advanced visualization indirectly led to progressively thinner CT slices and more MRI sequences, resulting in an explosion in the number of images available for the radiologist's review.

Structured and Automated Reporting

Structured reporting is a "Holy Grail" of sorts in imaging informatics, in an effort to make reports more concise, standardized, and useful in performance tracking. The ACR's BI-RADS®, initially created in 1993 and refined over the years,[4] has had a major positive impact on patient care in mammography. Indeed, it has spawned highly structured reporting schemas for lung, ovarian, liver, and prostate imaging.

Automated reporting that eliminates the need for transcriptionists, was also a major advance to reduce report turnaround times. Early automated systems, such as Paul Wheeler's innovative but complex reporting system at Johns Hopkins Hospital in Baltimore, MD,[5] was met with little enthusiasm in 1976. Speech recognition systems for radiology were initially described in the mid-1980s, but they did not come into widespread use until the late 1990s, when most radiologists had made the transition to automated reporting systems, albeit some, begrudgingly. However, major improvements in accuracy made possible by deep learning systems for speech recognition have resulted in much greater performance and acceptance of these systems.

The progress of computer aided detection and diagnosis (CAD) made possible by the transition from film to digital imaging has been surprisingly slow, given that filmless radiology has now been around for more than a quarter-century. The University of Chicago was conducting early mammography CAD research in the mid-1980s,[6] and an explosion of studies demonstrating expert-level performance of CAD in mammography then appeared in the 1990s. The use of CAD in mammography became widespread in 2003, when reimbursement was approved at about $12 per study. Unfortunately, owing to a combination of factors—probably related to how mammography CAD was being implemented—its actual perceived clinical usefulness was surprisingly low.

AI Comes to Radiology

The current era of exponential advances in AI began with the realization that graphics processing units used in video gaming could be applied to accelerate a type of neural network, resulting in "deep learning." This essentially meant that painstaking methods of "hand-crafted" image segmentation, feature recognition, and machine learning could be replaced by a technique that could create an algorithm directly from large datasets of annotated images in just hours, rather than months or years. The result: a veritable deluge of academic and commercial algorithms for hundreds of different types of image segmentation, detection, diagnostic, and quantification tasks.

Machine learning has also facilitated quantitative measurements of advanced images, such as prostate and brain MR images, to help discern patterns in the pixel data analogous to pattern detection in genomic analysis—hence, the term "radiomics." Despite initial concerns that AI might replace radiologists, the consensus now is that AI will instead improve radiologists' productivity and diagnostic accuracy, as well as reduce imaging times and radiation dose.

More Growth Ahead

I do not anticipate the pace of imaging informatics development to slow anytime soon, and I am very optimistic about the next 50 years. We will continue to see radiologists' efficiency improve by more than 50 percent as they focus more on judgment than detection, with pertinent information automatically extracted from multiple patient EMRs and meaningful tracking of follow-up of recommendations and important incidental findings.

More attention will be paid to radiologist cognitive overload, burnout, and stress. Population health detection of incidental findings and expanded screening will increasingly support "whole health" initiatives. Augmented reality will permit virtually any location to serve as a reading room. AI will become seamlessly integrated into new workflows that will go beyond the traditional PACS model and become a routine and trusted partner in detection, diagnosis, and follow-up.

I wouldn't be at all surprised if today's "Rip van Winkle" radiologist wakes up at *Applied Radiology*'s 100th anniversary to find even more dramatic changes in our specialty, thanks to advances in informatics. Sweet dreams.

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