Decoding the Digital X-Ray Environment: What's In It for Me?

Todd Boyland, CPSM

Digital imaging, once such a cutting-edge technology, has become commonplace and has slowly been replacing film operations in many facilities over the past decade. Vendors are now releasing second- and third-generation digital imaging equipment. Digital equipment is even working its way into facilities that once considered digital to be cost-prohibitive and out of reach.

This article is designed to demystify much of the digital technology that is becoming readily available, even for smaller independent imaging centers as well as major healthcare providers.

With all of the increased capital investment in digital technology, what are the benefits to the healthcare provider, and more importantly, to the patient? We'll discuss some of the benefits to the facility as well as the patient that include, but are not limited to: image processing, workflow efficiency, image availability, image quality, report turnaround time, and decreased patient anxiety.

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Image Post-Processing

The ability to manipulate the images after acquisition is the first benefit that comes to mind when discussing digital imaging. Post-processing features can include:

- Window width and window level adjustments. These allow the user to adjust the "width" of grayscale (contrast) visible for the image, while "level" adjusts the level (density) of each image. When considering detector and monitor matching, zooming is a factor that is widely overlooked. A high-resolution digital detector might have a 4,000 x 3,000 matrix. This literally means there are 4,000 pixels in one direction (horizontal) and 3,000 pixels in the other direction (vertical). This calculates to a 12 mega-pixel image, or 12 million pixels in the image. A standard laptop monitor might have a 1,280 x 768 pixels/resolution, which calculates to a .98 mega-pixel, or .98 million pixels total. If you were to look at the 12 mega-pixel image on the laptop monitor mentioned, and then selected fit-to-screen (which forces the entire image to be displayed on the monitor), you would be looking at a 1/12 decimation of the image. This means that only one out of 12 pixels would be visible in full screen mode. The use of the zoom tool in this case would be necessary to give a more accurate depiction of the actual image without losing any information. A 10:1 zoom would still not display every pixel on the monitor since the difference between detector and monitor is actually 12:1.
- Masking and shuttering allow the diagnosing physician to "mask" the outside edges of the im-

ABOUT THE AUTHOR
Todd Boyland is chief information officer with RSTI, where he serves as lead instructor for RSTI's picture archiving and communication systems (PACS) engineer/administrator certification series. He also teaches courses in analog and digital mammography, computed radiography, and digital radiography systems. He holds a certified PACS system manager (CPSM) certification.

age using software, much like collimation blocks unnecessary radiation from reaching a film receptor. Masking eliminates white areas surrounding the image that collimation may have missed. This gives the physician better ambient light conditions while diagnosing.

- Inversion is the ability to invert the image. Inversion is helpful to many physicians to help visualize certain pathologies that were not apparent to the human eye at first glance.
- Spatial transformations are simply the ability to rotate, flip, mirror, etc. the image. These transformations can be useful to the diagnosing physician.
- Annotations by definition are additions to a document. Image annotations can take many forms and include the following:
  - Labels
  - Markers – to mark patient laterality (right/left)
  - Measurements – distance, angles, etc.
  - Regions of interest
  - Patient demographics – Name, height, weight, etc.
  - Facility information

  Annotations can be either anchored or not anchored. An anchored annotation is subject to spatial transformations like flip, rotate, etc. Imagine that you made a measurement of a particular anatomy and then flipped the image horizontally. You would want your measurements to stay "anchored" to the anatomy that you were trying to measure and thus flip with the image. These types of annotations are anchored. Now imagine that you added a note to the image as an annotation that included patient history and pertinent diagnosis information. If you flipped the image, you would obviously not want this note to flip over as it would now be backwards text. Text annotations are not anchored as they will remain in the same position regardless of spatial transformations. Examples of non-anchored annotations include patient demographics, facility information, notes, etc.

Workflow Efficiency

Workflow in the medical world is defined as the interaction of people and information. Workflow mapping should be performed prior to implementing different components of digital imaging equipment. Performing workflow mapping is done by creating a detailed sequence of events that a person must go through to perform his/her job. Workflow mapping can be very useful in pinpointing bottlenecks in productivity and determining where digital technology can help improve workflow.

Some of the obvious contributions to workflow improvements come from DICOM Modality Worklist (MWL) and Modality Performed Procedure Step (MPPS). DICOM (Digital Imaging and Communications in Medicine) is a medical imaging standard that was developed by the American College of Radiology/National Electrical Manufacturers Association (ACR/NEMA). DICOM is designed to standardize the communication of digital medical information from machine to machine regardless of device manufacturer. MWL and MPPS are just two functions of DICOM that are designed to improve connectivity and sharing of patient information between different vendors' equipment.

DICOM MWL provides the equipment operator a list of scheduled exams that are yet to be performed. The scheduling information is entered in the Radiology Information System (RIS) scheduling software by the scheduling department. Each scheduled exam is assigned a performing physician, patient ID, accession number, scheduled start date, scheduled start time, and much more scheduling information. One of the important entries by the scheduling department is to identify the modality code for the exam to be performed. The modality code is a two-letter code assigned to that exam. Modalities use this code to query for their scheduled patients. Examples include:

- US – Ultrasound
- MG – Mammography
- CT – Computed Tomography
- XA – X-Ray Angiography
- MR – Magnetic Resonance Imaging
- RT – Radiation Therapy
- NM – Nuclear Medicine
- OT – Other

Imagine that a patient enters the facility for an ultrasound, but the scheduling department schedules the exam as "OT" for other. When the ultrasound modality queries for scheduled exams, it only wants to see scheduled ultrasound exams. The ultrasound will search only for exams with a modality code of "US." Since this patient was scheduled under "OT," it will not appear on the worklist. The ability to download the scheduled information using DICOM MWL drastically reduces input errors like this and saves correction times down the road. The MWL displays a list of scheduled exams on the modality so that the performing technologist can choose from a menu, thereby avoiding manual entry of the data, reducing errors. When the Modality Worklist function is down (either for scheduled reasons like upgrades, or for unscheduled reasons), the technologist is responsible for entering all patient information via the keyboard; mistakes can increase exponentially.

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DICOM MPPS (Modality Performed Procedure Step) is designed to complement MWL. Where MWL provides information about *scheduled* exams, MPPS provides information about *completed* exams. MPPS enables the modality that completed the exam to send a report with information about the exam such as duration, number of images acquired, dose administered to the patient, and other exam-specific statistics.

Workflow efficiency has many benefits. Employees can be more efficient at their jobs, which allows more patients to be processed. More patients being processed in a shorter period of time means that the average exam time can also be reduced, greatly improving patient care by reducing patient anxiety and increasing peace of mind.

Immediate Image Transfer to Multiple Destinations

Once the technologist performs the QC to ensure proper image quality, technique, etc., images that have been acquired digitally can be transferred immediately to multiple destinations, so they can be in more than one place at a time. With film there was typically only one copy of each image that required a courier for physical transport. Destinations for digital images can include:

- PACS (Picture Archive and Communications System), an archive server that is designed for short-term image storage
- Physicians review station for diagnosis
- Laser printers for transport to facilities that do not have digital reading equipment
- CD burners to allow the patient to leave with copies of his/her exam
- Other options such as off-site radiology firms that charge on a per-case basis for reporting. This is a great example of telemedicine where the imaging department might not even staff an in-house radiologist, but instead send the images offsite to be read.

Image Quality

It is commonly assumed that digital images must have better image quality that analog film images. As a general rule, resolution of digital images is typically degraded compared to film. This loss of image quality is due to the fact that, as mentioned before when discussing the detector matrix, the digital detector is made of small pixel elements. Any pathology that is smaller than the actual pixel itself cannot be resolved by the detector.

Typical pixel sizes can range between 50 micrometers (high resolution) to 250 micrometers and larger for lower-resolution systems. For reference, a human hair is said to be around 50 micrometers wide. A detector with a 100 micrometer pixel size is limited to a resolution of 5 lp/mm (line pairs per millimeter). Many digital systems cannot resolve more then 5-6 lp/mm due to limitations in pixel size. This is not to say that detectors cannot be produced with smaller pixels, thus allowing better resolution. Rather, consider the amount of data that the computer has to calculate and how long it would take the computer to make the image preview-ready. Most often today, the actual PC is most likely the limiting factor. Higher-resolution detectors are available, but the computer power/cost to process these images is cost prohibitive to manufacturers.

That being said about resolution, what about contrast? Contrast is the area where digital makes major improvements over film images. Digital detectors convert x-rays into electrons; this is the job of all digital detectors. These electrons (analog) need to be converted into digital signals for the computer to process. The analog to digital (A/D) converter performs this task. A/Ds of many different bit depths are used in digital imaging. An 8-bit A/D can convert a voltage into 256 possible values, which can be 256 different shades of grey on a monitor. Ultrasound uses 8-bit A/Ds; this fact explains why ultrasound images are either very black or very white, but not much grey in the middle compared to other modalities. CR and DR typically use 12-bit A/D, which allows 4096 shades of grey. A typical MRI A/D could be 16-bit, allowing 65,536 different shades of grey. More shades of grey mean more contrast available for the image, but also more information to process, store, and transport.

These examples show that digital has a very wide dynamic range compared to film images. If a physician isn't satisfied with the contrast of a film image, the only option is to re-expose the image, with minor corrections possible by adjusting light conditions.

Reporting Turnaround Time

Most people working in diagnostic imaging service tend to forget that the actual goal of this entire process is for the physician to make a diagnosis and generate a report. We in the service profession focus on getting the exams taken and making sure the equipment operates smoothly, forgetting that the process is only half complete at that point. The report is the actual final product of the diagnostic imaging center. It is the reason why the patient is coming through the diagnostic imaging department in the first place. The goal of the technology and efficiency improvements we've discussed so far are to ensure that the diagnosing physician receives the preliminary results in a more timely fashion and is able to use all available tools to make the most accurate diagnosis the first time. Improved patient care is the ultimate result.

Conclusion

Each of these advancements in digital imaging provide benefits to everyone involved, including:

- Technologist: Acquiring the exam becomes more streamlined. For example, the Modality Worklist eliminates the need for the technologist to manually enter patient demographic information into the system. Patient information, as well as exam details such as technique used, date, time, etc. are now populated automatically by the Worklist and the digital modality itself.
- Radiologist: Reading the exam becomes easier and more accurate with the benefits of CAD (computer aided detection/diagnosis). Improved image quality leads to a more accurate diagnosis. The ability for digital images to be in more than one physical location at one time also means that more than one physician can access the images simultaneously.
- Patient: The benefits to the patient are the most important, as well as the most difficult to quantify. The benefits can be found in increased image quality leading to a more accurate diagnosis. The ability of the facility to minimize the report turnaround time means that the diagnosis can get back to the patient much more quickly, reducing patient wait time and anxiety. ■