Practical Imaging Informatics
Practical Imaging Informatics

Foundations and Applications for PACS Professionals
For the four who laid the flagstones
And the three who walk behind,
  Eyes wide with wonder

And for Cara
Always for Cara

BFB

To my wife Terry, a font of affection and inspiration.

DLR

This book is dedicated to my family, your love and support strengthens me.
Philippians 4:13.

DSG

To my wife Janet, for her transcendent love, encouragement, and support.

DLW

The Editors are indebted to Ms. Caroline Wilson; without her tireless efforts, this book never would have come to fruition.
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Introduction

Barton F. Branstetter IV

The Evolution of the Imaging Informatics Professional

Within the last decade, medicine has undergone a dramatic transformation to a digital environment. Radiology has been at the leading edge of this change, with Picture Archiving and Communication Systems (PACS) becoming almost ubiquitous across the United States. As PACS developed and matured and became a mission-critical component of patient care, radiologists realized that a dedicated team of individuals would be needed to ensure that the PACS functioned continuously and reliably.

But where to find these individuals? A strong computer background would be essential, but a computer programmer or IT professional might not understand the clinical needs that underlie the PACS. After all, most IT systems do not require support that is timely and urgent, with patient-care decisions hanging in the balance. Changing from the IT culture to the medical culture can be difficult. So, a clinical background (e.g., technologists, nurses) is also critical. But relatively few people in these careers had the computer background to maintain a system as complex as a PACS. Even fewer had an interest in switching to an untested and uncertain career path.

Thus was born the PACS administrator – that rare breed with knowledge of both clinical workflow and information technology. Unfortunately, there were not enough people with the requisite skills to fill these roles. A few motivated, self-taught individuals from a variety of backgrounds found ways to fill the gaps in their own knowledge and become a bridge between the clinical and IT communities.

As PACS evolved, so did the training and background required of a PACS administrator. Keeping the PACS working was no longer sufficient – the ability to improve the PACS, work with the vendors, and even make the PACS communicate with other IT infrastructure in the hospital became critical to the job. Other specialties outside of radiology began to need similar services, and the obvious person to play that role was the PACS administrator.

But, this transition was not easy. Not only was the traditional training inadequate, the terminology describing the job was also inadequate. Seeing that the knowledge base developed in radiology was becoming needed
throughout the medical enterprise, the Society for Computer Applications in Radiology transformed itself into the Society for Imaging Informatics in Medicine, and the PACS administrator was transformed into the Imaging Informatics Professional (IIP), who has responsibilities far beyond the boundaries of the PACS itself.

With the new terminology, the core knowledge needed for the job had widened. The clinical knowledge base had widened to include medical specialties outside of radiology, and the IT knowledge base required an understanding of software interactions and networking across the entire enterprise. Who can fill this role? Who has the skills and knowledge to do the job? How can employers be sure that applicants for an IIP position will be able to serve the physicians and patients who are the ultimate clients of the digital infrastructure?

That is where certifying organizations such as the American Board of Imaging Informatics (ABII) come in. This organization, and others like it, was created to certify individuals from varying backgrounds in IT and clinical care, and to ensure that everyone who calls themselves an IIP has the knowledge and skills needed not just to keep the PACS afloat but also to keep the entire medical imaging infrastructure running smoothly, and improve efficiency for the whole medical enterprise.

**Who Should Read This Book**

The primary audience for this book is Imaging Informatics Professionals (and those who want to become IIPs). A certification test, such as the Certified Imaging Informatics Professional (CIIP) test offered by the ABII, is certainly a good reason to master the wealth of information in this book! But, it is worth noting that this book, like all educational programs offered by the Society for Imaging Informatics in Medicine (SIIM), is independent of the ABII and the CIIP certification program. The authors of this book do not have any inside information about the CIIP test.

Hopefully, this book will also be useful to IIPs long after the test is completed and passed, as a reference and troubleshooting guide for everyday imaging informatics. The layout and format of the book are designed with one major purpose in mind: quick reference. Our goal was to make sure that anyone who had read the book could look up a critical piece of information in the minimum amount of time. If you flip to the correct chapter, the key words and key concepts should jump out at you, and hopefully, the information you need should be right there, easy to find. Important definitions, checklists, and concepts are set off in color-coded boxes that draw the reader’s eye. Sources of additional information are clearly highlighted. IIPs are masters of workflow efficiency, so the textbook that supports them had better be efficient to use!
Although IIPs are the primary audience for this book, other professionals will hopefully find it useful. IT staff working in medicine, even if not in the formal role of PACS administrator, will benefit from understanding the clinical references that pervade their work. Physicians and trainees interested in informatics will find the information pertinent to their practice, and the knowledge base formed by reading this book can serve as a basis for more in-depth study. Administrators supervising or hiring IIPs may also find the book of use, to better communicate with those who are maintaining the digital infrastructure.

The Organization of This Book

The book is divided into six sections. The first two sections are the foundations sections, in which the basics of information technology and clinical image management are introduced. Depending on your background, some of these chapters may seem overly simplistic. The goal of these sections is to bring everyone up speed on areas of knowledge that they might not bring with them from their previous fields of study.

The third and fourth sections of the book are devoted to daily operations – the issues that arise on a day-to-day basis for IIPs, like customer relations and downtime procedures. These sections also contain chapters about the clinical environment in which images are used and interpreted.

The fifth and sixth sections deal with administrative issues that arise less frequently, but have a major impact on the life of the IIP. Decisions such as choosing a PACS vendor and long-range strategic planning fall into these sections of the book.

The field of imaging informatics is rapidly changing. As with all technological fields, newer and better software and solutions are continually developed. No printed textbook can be completely current or exhaustive on topics such as these. The purpose of this book is to answer commonly asked questions and provide a basis for continuous learning. To this end, many of the suggested readings in the chapters are links to websites that are likely to be updated as technology improves.

It is important to remember that every hospital or imaging site is unique. Solutions that work in one location may be totally inappropriate for other enterprises, or even elsewhere within the same enterprise. But some shared themes run through all of medical imaging; hopefully, we have focused on those in this book.

The bottom line – our main goal – was to provide pertinent information to IIPs at the point when it matters most (in medical terminology, “support at the point of care”). With this book at your desk, you should be able to rapidly find the information you need to troubleshoot urgent situations – the sorts of situations faced every day by Imaging Informatics Professionals.
Part I
Technology: Getting Started
Associate Editor: Daniel L. Rubin
Chapter 1
Medical Imaging Modalities and Digital Images

Katherine P. Andriole

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1.1 Introduction

1.1.1 Special Aspects of Medical Images

Medical imaging technologies enable views of the internal structure and function of the human body. Information obtained from the various modalities can be used to diagnose abnormalities, guide therapeutic procedures, and monitor disease treatment. Medical images have unique performance requirements, safety restrictions, characteristic attributes, and technical limitations that often make them more difficult to create, acquire, manipulate, manage, and interpret. Some of these contributing factors include...
• Complexity of imaging situations due to equipment size and available space, inaccessibility of the internal structures of the body to measurement, patient positioning, patient illness, and procedure practicality.
• **Variability** of the data between patients; for example, between normal and abnormal anatomy and physiology, within normal range, and within the same patient at different times or body positions.
• Effect of imaging transducer on the image, including artifacts created by the imaging method or by something in the patient’s body. A major source of artifact in images of living systems is motion.
• Safety considerations, patient discomfort, procedure time, and cost–benefit tradeoffs.

### 1.1.2 Medical Imaging Terminology

**Medical Imaging Hierarchy:** Patient – Examination (Study) – Series (Sequence) – Image. For example, a patient may undergo an imaging examination, also called a study, such as computed tomography (CT) of the abdomen. This study may include several sequences or series, such as the set of images with and the set without contrast. A sequence or series may consist of a single image or multiple images.

• Modalities can be characterized by whether their energy source uses **ionizing radiation** such as for radiography, fluoroscopy, mammography, CT, and nuclear medicine or non-ionizing radiation such as for ultrasound and magnetic resonance imaging (MRI).
• **Projection** (planar) imaging, such as projection radiography in which X-rays from a source pass through the patient and are detected on the opposite side of the body, produces a simple two-dimensional (2-D) shadow representation of the tissues lying between the source and the detector. Each point in the image has contributions from all objects in the body along a straight line trajectory through the patient. Overlapping layers of tissues can make planar imaging difficult to interpret.
• **Tomographic** (cross-sectional) imaging modalities include CT, MRI, and ultrasound. In CT, for example, the X-ray source is tightly collimated to

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**Definition 1.1: Artifact**

Any component of the image that is extraneous to the representation of tissue structures; can be caused by a technique, technology, hardware, or software error.

**Definition 1.2: Ionizing Radiation**

Radiation capable of producing energetic charged particles that move through space from one object to another where the energy is absorbed; may be hazardous if used improperly.
interrogate a thin transverse section through the body. The source and detectors rotate together around the patient producing a series of one-dimensional projections at a number of different angles. The projection data are mathematically reconstructed to create a 2-D image of a slice through the body. Digital geometric processing can be used to generate a three-dimensional (3-D) image of the inside of objects from a series of 2-D image slices taken around a single axis of rotation. Historically, images have been generated in the axial (transverse) plane that is orthogonal to the long axis of the body. Today’s modern scanners can reformat the data in any orientation (orthogonal or oblique to the body axis) or as a volumetric representation.

- Medical modalities produce representations of anatomical (structural) or molecular/physiological (functional) information of the imaged body parts. For example, X-ray images are representations of the distribution of the linear attenuation coefficients of tissues and are largely images of anatomy or the structural nature of the tissues in the body. Radioisotope imaging of nuclear medicine produces images of the distribution of chemical, molecular, or physiological function of the tissue. Some modalities, such as ultrasound, can provide other types of functional measures, such as flow through vessels.

**Key Concept 1.3: Imaging Modalities**

Modalities can be characterized by their energy source as invasive (using ionizing radiation) or non-invasive. They are acquired in 2-D planar projection mode or tomographic cross-section; and produce images representative of anatomical structure and/or physiological or molecular function.

**Key Concept 1.4: X-Ray Attenuation**

Attenuation of an X-ray beam is largely a function of tissue radiodensity. Bone, for example, has a higher attenuation coefficient than soft tissue. In a radiograph of the chest, bony structures highly attenuate (or absorb) X-rays, passing less signal through the body to the detector; whereas soft tissues are less attenuating, passing more signal through to the detector. Air is least attenuating, and thus high signal hits the detector and is represented as black in most images; no signal hitting the detector is usually represented as white. In a chest radiograph, the air spaces in the lungs appear black, soft tissues are lighter gray, and the bony ribs and spine are white.

### 1.2 Diagnostic Imaging Modalities

For each diagnostic modality given below, the energy source and detector used in image formation are listed along with the tissue characteristic or attribute represented by the modality. Advantages and disadvantages for each are included.
1.2.1 Projection Radiography

- Source: X-rays; ionizing radiation; part of the electromagnetic spectrum emitted as a result of bombardment of a tungsten anode by free electrons from a cathode.
- Analog detector: fluorescent screen and radiographic film.
- Digital detector: computed radiography (CR) uses a photostimulable or storage phosphor imaging plate; direct digital radiography (DR) devices convert X-ray energy to electron–hole pairs in an amorphous selenium photoconductor, which are read out by a thin-film transistor (TFT) array of amorphous silicon (Am-Si). For indirect DR devices, light is generated using an X-ray sensitive phosphor and converted to a proportional charge in a photodiode (e.g., cesium iodide scintillator) and read out by a charge-coupled device (CCD) or flat panel Am-Si TFT array.
- Image attributes: variations in the grayscale of the image represent the X-ray attenuation or density of tissues; bone absorbs large amounts of radiation allowing less signal to reach the detector, resulting in white or bright areas of the image; air has the least attenuation causing maximum signal to reach the detector, resulting in black or dark areas of the image.
- Advantages: fast and easy to perform; equipment is relatively inexpensive and widely available; low amounts of radiation; high spatial resolution capability. Particularly useful for assessing the parts of the body that have inherently high contrast resolution but require fine detail such as for imaging the chest or skeletal system.
- Disadvantages: poor differentiation of low contrast objects; superposition of structures makes image interpretation difficult; uses ionizing radiation.

1.2.2 Fluorography

- Source: continuous low-power X-ray beam; ionizing radiation.
- Detector: X-ray image intensifier amplifies the output image.

Further Reading 1.5: Physics of Medical Imaging


Thought Problem 1.6: Radiation Dose

Exposure to radiation at excessive doses can damage living tissue. Note however that the radiation exposure for a chest X-ray in the diagnostic range is equivalent to the amount of radiation exposure one experiences over a 10-day period from natural surroundings alone.
• Image attributes: **continuous acquisition of a sequence of X-ray images** over time results in a real-time X-ray movie.
• May use inverted grayscale (white for air; black for bones).
• Advantages: Can image anatomic motion and provide real-time image feedback during procedures. Useful for monitoring and carrying out barium studies of the gastrointestinal tract, arteriography, and interventional procedures such as positioning catheters.
• Disadvantages: Lower quality moving projection radiograph.

### 1.2.3 Computed Tomography (CT)

• **Source:** collimated X-ray beam; X-ray tube rotates around the patient.
• **Detector:** early sensors were scintillation detectors with photomultiplier tubes excited by sodium iodide (NaI) crystals; modern detectors are solid-state scintillators coupled to photodiodes or are filled with low-pressure xenon gas. An image is obtained by computer processing of the digital readings of the detectors.
• **Image attributes:** thin transverse sections of the body are acquired representing an absorption pattern or X-ray attenuation of each tissue. Absorption values are expressed as **Hounsfield Units**.
• **Advantages:** **good contrast resolution** allowing differentiation of tissues with similar physical densities; **tomographic acquisition** eliminates the superposition of images of overlapping structures; advanced scanners can produce images that can be viewed in multiple planes or as volumes. Any region of the body can be scanned; has become diagnostic modality of choice for a large number of disease entities; useful for tumor staging.
• **Disadvantages:** high cost of equipment and procedure; high dose of ionizing radiation per examination; artifacts from high contrast objects in the body such as bone or devices.

#### Definition 1.7: Hounsfield Unit
CT number representing absorption values of tissues; expressed on a scale of +1000 units for the maximum X-ray beam absorption of bone to −1000 units for the least absorbent air. Water is used as a reference material for determining CT numbers and is, by definition, equal to 0.

### 1.2.4 Magnetic Resonance Imaging (MRI)

• **Source:** **high-intensity magnetic field**: typically, helium-cooled superconducting magnets are used today; non-ionizing; gradient coils turn **radiofrequency (RF) pulses** on/off.
Detector: phased array receiver coils capable of acquiring multiple channels of data in parallel.

- Image attributes: produces images of the body by utilizing the magnetic properties of certain nuclei, predominately hydrogen (H\(^+\)) in water and fat molecules; the response of magnetized tissue when perturbed by an RF pulse varies between tissues and is different for pathological tissue as compared to normal.

- Advantages: non-ionizing radiation, originally called nuclear magnetic resonance (NMR) but because the word “nuclear” was associated with ionizing radiation, the name was changed to emphasize the modality’s safety; can image in any plane; has excellent soft tissue contrast detail; visualizes blood vessels without contrast; no bony artifact since no signal from bone; particularly useful in neurological, cardiovascular, musculoskeletal, and oncological imaging.

- Disadvantages: high purchase and operating costs; lengthy scan time; more difficult for some patients to tolerate; poor images of lung fields; inability to show calcification; contraindicated in patients with pacemakers or metallic foreign bodies.

1.2.5 Nuclear Medicine and Positron Emission Tomography (PET)

- Source: X-ray or \(γ\)-ray emitting radioisotopes are injected, inhaled, or ingested; most common isotopes are technetium-99, thallium-201, and iodine-131.

- Detector: gamma camera with NaI scintillation crystal measures the radioactive decay of the active agent; emitted light is read by photomultiplier tubes; pulse arithmetic circuitry measures number and height of pulses. Further, these pulses are converted to electrical signal that is subsequently processed into a grayscale image.

- Image attributes: metabolic, chemical, or physiological interactions of the radioisotope are measured. The radioisotope chemical is distributed according to physiological function so the image primarily represents functional

### Key Concept 1.8: MRI Procedure

The patient is subjected to a magnetic field, which forces the H\(^+\) nuclei to align with the magnetic field; an excitation pulse of radiofrequency is applied to the nuclei, which perturbs them from their position; when the pulse is removed, the nuclei return to their original state releasing energy, which can be measured and converted to a grayscale image.

### Definition 1.9: SPECT

Single-Photon Emission Computed Tomography; a tomographic slice is reconstructed from photons emitted by the radioisotope in a nuclear medicine study.
information; however since function is distributed in the physical structures, recognizable anatomical images are produced.

- **Advantages:** measures targeted specific chemical-physiologic tissue function; valuable diagnostic tool particularly for imaging infarcts in the cardiovascular system, perfusion, and ventilation scanning of the respiratory tract for pulmonary embolus, imaging uptake at sites of increased bone turnover as in arthritis and tumors, assessing focal nodules, and in oncologic assessment.
- **Disadvantages:** high cost; PET isotopes require a cyclotron for production.

### 1.2.6 Ultrasound

- **Source:** high-frequency sound waves produced by a transducer made of a piezoelectric crystal.
- **Detector:** the source transducer also functions as a receiver of reflected sound and converts the signal into an electric current, which is subsequently processed into a grayscale image.
- **Image attributes:** sound waves travel through the body, are affected by the different types of tissues encountered and reflected back; a moving image is obtained as the transducer is passed across the body.
- **Advantages:** relatively low cost; non-ionizing energy source and safe; can scan in any plane; equipment is portable and can be used for bedside imaging; particularly useful for monitoring pregnancy, imaging the neonatal brain, visualizing the uterus, ovaries, liver, gallbladder, pancreas, and kidneys, confirming pleural effusions and masses, and assessing the thyroid, testes, and soft-tissue lesions.
- **Disadvantages:** operator-dependent; poor visualization of structures underlying bone or air; scattering of sound through fat yields poor images in obese patients.

### Definition 1.10: PET

Positron Emission Tomography uses cyclotron-produced positron-emitting isotopes including oxygen, carbon, nitrogen, and fluorine enabling accurate studies of blood flow and metabolism; positron isotopes are short-lived positively charged electrons; main clinical applications are in the brain, heart and tumors.

### Definition 1.11: Doppler Ultrasound

A technique to examine moving objects in the body. Blood flow velocities can be measured using the principle of a shift in reflected sound frequency produced by the moving objects. Can be used to image the cardiac chambers and valves of the heart, arterial flow, particularly to assess the carotids and peripheral vascular disease, and venous flow studies for the detection of deep-vein thrombosis.
1.2.7 Visible Light

- It is non-invasive but has limited ability to penetrate tissues deeply like the energies used in radiological imaging. Visible light imaging is used in light microscopy for pathological diagnosis, hematology, dermatology to photograph the skin, gastroenterology (colonoscopy/endoscopy), ophthalmology to image the retina, and during surgical procedures.

1.3 Digital Images

1.3.1 Definition

- A continuous image \( f(x,y) \) is a 2-D light intensity function \( f \) at spatial coordinates \( x,y \); the value \( f \) at location \( x,y \) is proportional to the brightness or grayscale of the image at that point.
- A digital image is an image \( d(x,y) \) that has been discretized (digitized) both in space (physical location) and in amplitude (gray level); it can be considered as a matrix whose row and column indices identify a point \( x_1,y_1 \) in the image, and the corresponding matrix element value \( d(x_1,y_1) \) identifies the gray level at that point. Elements in the digital array are called pixels for picture elements and each is represented by a numerical value in the computer. 3-D images consist of voxels or volume elements (Fig. 1.1).

![Graphical representations of a pixel and a voxel.](image)

Fig. 1.1 Graphical representations of a pixel and a voxel.

1.3.2 Digital Image Formation

- To be suitable for computer processing, an image function must be digitized both spatially and in amplitude. Image sampling is the digitization of the
spatial coordinates and is related to **pixel size**, reflective of matrix size and affects **spatial resolution**.

- Image gray level **quantization** is digitization of the amplitude or brightness, is determined by computer **bit depth**, and is reflected in the **image contrast resolution**.

- The process of digital image production includes **scanning** of the analog image line-by-line to obtain a continuous analog signal representing the variations in image brightness; followed by dividing the analog signal into individual pixels in a process known as **spatial sampling**, which is typically performed in equal intervals; this is followed by converting the amplitude into a digitized numerical pixel value in the process of **contrast quantization**; lastly, an **analog-to-digital (ADC) converter** turns the quantized level into binary code (Fig. 1.2).

![Image Formation Process](image.png)

**Fig. 1.2** The digital image formation process including scanning, sampling and quantization, and analog-to-digital conversion.

### 1.3.3 Image Quality Factors

- **Spatial resolution** limits sharpness (edges separating objects in the image) or visibility of fine detail and is a function of sampling that affects matrix and pixel size. Since each pixel can have only one numerical value, it is not possible to observe any anatomical detail within a pixel. More frequent sampling that results in smaller pixels (larger matrix sizes) provides better visibility of fine detail and a better quality higher spatial resolution image. If images are insufficiently sampled, the poorer resolution images may have a characteristic blockiness or checkerboard artifact.

- **Contrast resolution** limits differentiation of detail within and between objects and is a function of the bit depth used to represent the grayscale quantization. Insufficient quantization can result in false contouring or ridges in which smoothly varying regions of an object within the image become undifferentiable.

- **The total resolution of a digital image is the combination of the spatial resolution and the contrast resolution.** An image file size is equal to the product of
the matrix size (number of rows times number of columns) times the number of 8-bit bytes required to represent the image bit depth. For example, a CT slice is typically 512 rows by 512 columns and the grayscale is represented by 16 bits. It requires 2 bytes to account for 16 bits of grayscale, and therefore, a CT slice file size is then $512 \times 512 \times 2 = 524,288$ bytes or approximately half a megabyte (MB). A single-view chest radiograph is approximately 10 MB.

- **Noise** is a characteristic of all medical images; increased noise can lower image quality; noise is sometimes referred to as image mottle and gives the image a textured, snowy, or grainy appearance that can degrade visibility of small or low contrast objects. The source and amount of image noise depend on the imaging method; nuclear medicine images generally have the most noise, followed by MRI, CT, and ultrasound; radiography produces images with the least amount of noise.

### Pearls 1.13

- Medical images have special features that make them difficult to create, acquire, manipulate, manage, and interpret. Complexities include human variability, performance requirements, safety considerations, motion artifacts, technical limitations, and cost.
- Diagnostic imaging modalities are categorized by their sources (ionizing or non-ionizing radiation), acquisition mode (projection or cross-section), and tissue property measured (anatomic structure or molecular function).
- Medical imaging hierarchy includes patient, examination (study), series (sequence), image, and pixel.
- Digital images are discretized (digitized) by sampling in space (location) and quantizing in contrast (grayscale).
- Spatial resolution limits sharpness or visibility of fine detail and edges in the image; it is a function of sampling that affects matrix and pixel size.
- Contrast resolution limits the number of different colors or grayscales represented in the image and is a function of quantization bit depth.

### Suggested Reading


Self-Assessment Questions

1. Which of the following is the most significant source of artifact in medical images?
   a. Human variability
   b. Patient positioning
   c. X-ray dose
   d. Subject motion
   e. Safety considerations

2. Which of the following imaging modalities use ionizing radiation as its source?
   a. Magnetic Resonance Imaging
   b. Computed Tomography
   c. Ultrasound imaging
   d. All of the above
   E. None of the above

3. Which of the following modality is most affected by the skill of the operator?
   a. Projection radiography
   b. Ultrasound
   c. Computed Tomography
   d. Magnetic Resonance Imaging
   e. Positron Emission Tomography

4. In the formation of a digital image, sampling affects which of the following?
   a. Visible fine detail
   b. Image matrix size
   c. Spatial resolution
   d. All of the above
   e. None of the above

5. Which imaging modality provides higher spatial resolution?
   a. Chest radiograph
   b. Chest CT
Chapter 2
Computers and Networking

Adam Flanders

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2.1 Introduction

The core infrastructure of any modern Radiology department is made up of computers/computer workstations and the connectivity or networking capability between these devices. All transactions between modalities, PACS, scheduling, billing, dictation, and reporting systems are made possible through specialized computer programs or applications that are executed by computers. Computer systems are quite diverse and are often designed to augment a specific task, whether it is to support image reconstruction for a modality such as computed tomography (CT) or digital radiography (DR) or rapid image display as in PACS. Fundamentally, all computers are built around a similar base design with enhancements in specific areas to address certain needs such as rapid storage access and data transfer for file servers and improved video characteristics for PACS client display stations. The purpose of this chapter is to familiarize the reader with the fundamentals of computer architecture, networking, and computer applications.
2.2 Computers 101 – Hardware

2.2.1 Hardware Elements of Computers

- There are five core hardware components of the modern digital computer system: the central processing unit or CPU, memory, input devices, output devices, and a bus. While some components are given greater emphasis for a particular computer design (e.g., a faster CPU for computationally intensive tasks), virtually all types of computers have these five key components represented. Most of the hardware components in the modern digital computer are contained within small modular semiconductor packages (integrated circuits [ICs] or chip) that, in turn, contain millions of discrete components. Numerous ICs are interconnected on a large circuit board, frequently referred to as the motherboard. The motherboard is interfaced with other outside components (e.g., disk drives, power supply, keyboard, network, etc.) using specialized couplers that provide necessary power and connectivity to peripheral devices such as disk drives (storage), video displays, and keyboards.

- The central processing unit (CPU) or microprocessor is typically the largest integrated circuit on the motherboard and its role is to execute specific commands or instructions/machine code dictated by a computer program and orchestrate the movement of data and instructions through the entire computer system. Although the CPU is frequently personified as the “brain” of the computer, it has no innate “intelligence” or inherent ability to make decisions. The CPU’s strength is in its ability to process instructions and manipulate data at amazing speeds. In this regard, it is the perfect soldier; it follows all commands presented to it with blazing efficiency.

- The number of instructions that a CPU can perform per second is expressed as its clock speed. Typical personal computer CPUs can perform over 3 billion instructions per second or 3 gigahertz (3 GHz). Modern CPUs actually contain two to eight CPUs in one IC or chip (multi-core CPU). This provides unparalleled computational speed as each core shares the processing tasks formerly assigned to one CPU. While the strength of the CPU is in its ability to process instructions, it has limited capability to store data before or after execution. The CPU relies on physical memory to store this information and provides it to the CPU on demand.
Memory is principally used to temporarily store data (and results) and applications or programs. In contrast to the CPU, a memory module has no capability to process instructions; instead memory is designed to reliably store large chunks of data and then release these data on command (often at the behest of the CPU). Physical memory can exist in solid-state form as an IC or as physical media (spinning disk, compact disk [CD], or digital versatile disk [DVD]). A solid-state memory module that can be erased and rewritten for unlimited number of times is generically referred to as random access memory or RAM.

- Memory that can only retain data with power applied is referred to as volatile memory – most of the motherboard memory modules are of this type. These are rated by their storage capacity (given in megabytes or gigabytes), access speed (in nanoseconds), data rate (DDR2), and configuration (single or dual inline memory SIMM or DIMM).

- Non-volatile memory will retain data written to it until it is erased or over-written. Examples include USB memory sticks and disk drives. Since the inherent speed of non-volatile memory is substantially slower than that of volatile memory, volatile RAM is typically employed on the motherboard to augment data processing.

- Some forms of memory are designed for specific tasks. Video memory (VRAM) is employed on video graphics cards to store graphical information to improve video display performance. A specialized form of high-performance memory is found on most CPUs to help efficiently buffer data that move in and out of the microprocessor core (L2 cache memory).

- There are additional forms of computer memory that are classified simply as storage, principally because they are characterized by slower speed compared to solid-state memory and non-volatile characteristics (data persist indefinitely until erased/overwritten). These are made up of spinning media (disk drives, CDs, and DVDs) and linear media (tape).

- On-line storage refers to high-performance, non-removable media that requires no human or mechanical intervention to retrieve. Data on spinning hard disk arrays are an example of on-line storage. Near-line storage consists of removable media (e.g., tapes, CDs, or DVDs) that are made available through mechanical means such as a robotic tape or optical disk jukebox. The efficiency of data retrieval with a near-line system is dependant upon the mechanical speed of the robotic system and the queuing mechanism of the media. Off-line storage is removable media that requires human intervention to load and retrieve data. As a result, performance
is the lowest for off-line storage. While off-line storage is the least expensive storage strategy, it is otherwise quite inefficient and is therefore reserved for data that have a low probability for future use.

- **Input/output devices** are hardware extensions that allow humans (or other devices) to interact with a computer. Examples of input devices include the keyboard, touch screen, mouse, microphone, and camera. Typical output devices include the video display, printer, plotter, and speaker.

- Because the typical microprocessor can execute several billions of commands per second, it is highly dependant upon an efficient mechanism for delivering instructions and data to it. This requires that there is a well-orchestrated method for moving data between the motherboard components and the CPU. The **data bus** is the physical data chain built into the motherboard that allows for this efficient data transfer. This is supported by several ICs, known as the **chipset**, which coordinates uninterrupted data transfers through the bus. Multiple different designs have been developed; the most common in use today is peripheral component interconnect (PCI) and PCI-Express. The data bus is defined by a **data-width** (typically 32 or 64 bits), which specifies how much data are delivered across the bus per cycle and a **clock speed** (given in megahertz).

- Another key component to the typical computer motherboard is the **basic input/output system (BIOS)**. The BIOS is comprised of a non-erasable read only memory (ROM) chip that contains the minimal amount of software necessary to instruct the computer how to access the keyboard, mouse, display, disk drives, and communications ports.

- When the power is first applied to the computer, the motherboard relies on the BIOS to tell what additional components are available to the motherboard for input and output (e.g., disk drives, memory, keyboard, etc.). The motherboard “becomes aware” of what is available and how to access it, each and every time the computer is restarted.

- The BIOS also provides information to the motherboard on where to find the first piece of software to load during the startup process. The startup process is also known as the **boot process**. The first piece of software to load is usually a portion of the **operating system** that will coordinate the other software programs.
2.3 Computers 101 – Software

- Hardware can be seen and handled. Software, on the other hand, is a virtual concept. While we can handle the media that software is written on, we cannot actually “see” the software.
- The term “software” applies both to application programs and data.
- Software at its lowest level (the level at which it interacts with the CPU) consists of a long series of bits (ones and zeros). All data written to physical media, whether it is magnetic disk, USB stick, CD, DVD, or RAM memory is stored as an orderly series of bits. Eight-bit clusters of data form a byte of data.
- Software is divided into system software (or operating system) and application software – programs that help users to perform specific tasks and programming software (or development software) – programs that aid in the writing (i.e., coding) of other software.
- All software consists of individual procedures that command the computer to follow a precisely orchestrated series of instructions. The number of individual instructions specified in any one program varies depending upon the type and complexity of the software – from 10 to 100 million lines of code. (The Windows XP operating system, for example, contains approximately 40 million lines of code.)
- All computer software must be moved into storage (i.e., disk drive) or physical memory (RAM) before it can be executed by the microprocessor. The instructions are passed through a series of software layers where they ultimately reach the microprocessor. Each instruction causes the computer to perform one or more operations.

2.3.1 Computer Operating System

- The operating system (OS) is the underlying software that integrates the hardware with software applications. It is distinguished from the essential hardware components in that it consists entirely of software – millions of lines of machine commands that are understood and obeyed by the microprocessor. The OS actually consists of hundreds or thousands of individual programs that bundled together. Many of these individual programs are
designed to work cooperatively with each other. The OS is automatically executed each time the computer is started and it is the most important software component running on any computer. A modern computer cannot operate without an OS.

- Although the CPU is frequently personified as the “brain” of the computer, it is really the OS software and the CPU acting together that provides the underlying “intelligence” of system. The OS and the CPU are inexorably linked; therefore, the distinction between the software and the hardware is sometimes blurred.

- The OS is designed to automatically manage nearly every task (or process) including maintenance of the files on the disk, tracking input from peripheral devices like keyboards or network cards, displaying output on printers and video displays and control of memory allocation. Memory allocation is crucial for maintaining stability of the system because if two programs try to use the same area of memory, both programs will usually fail. Two of the most critical jobs of the OS are ensuring that programs do not unintentionally interfere with each other and maintaining security.

- A function paramount to the modern OS is the support of the graphical user interface (GUI). A GUI replaces typed computer commands with a graphical representation of the task (e.g., moving a file). This is accomplished by creating a visual representation of the computer file system (the desktop), icons, and windows and linking them to the movements of a pointing device such as a mouse or trackball.

- The OS also provides a foundation or software platform for all other software (application programs). Therefore, the choice of OS, to a large extent, determines which application software can be used on a particular system.

- There are a number of operating systems in use today. The most popular is the Windows OS (Microsoft, Redmond Washington) that runs on the majority of computers worldwide. Other choices include UNIX, Linux, DOS, and the Mac OS (Macintosh).

- A multiprocessing OS supports use of more than one CPU. A multitasking OS allows more than one program to run simultaneously. A multithreading OS allows different parts of a program to run concurrently and a multi-user OS supports two or more individuals to run programs concurrently on the same computer system.

- An OS may consist of hundreds (or even thousands) of small programs called drivers. Drivers enable software to interact with the ubiquitous hardware devices attached to the motherboard and between

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**Key Concept 2.6: Drivers**

Drivers are small programs that enable the operating system and application programs to interact with each other and with peripheral hardware devices. They require periodic upgrades, especially when the OS changes.
components on the motherboard itself. In other instances, drivers allow one software component to safely interact with another piece of software.

- From the user perspective, the OS provides the framework that application software runs inside of. All application software runs on top of the OS that, in turn, is directly integrated to the hardware. In general, application software cannot interact directly with the hardware; it must work through the OS. The modern OS is intentionally designed to sustain itself automatically with minimal user interaction. The software that is designed to perform real work for users is the application software.

2.3.2 Application Software

- OS software is designed to run autonomously with little interaction from the individual user. The OS monitors all internal functions of the computer, maintains stability of the hardware components, and regulates the processing of data in the microprocessor. **Application software** is a program designed to do real work for a user. Application software does not supplant the base OS software. Instead, application software runs on top of the OS such that an application is written (or coded) to work with a specific OS. Examples of application software include a word processor or spreadsheet.

2.3.3 Low-Level Programming Language

- Low-level programming language is the software language that is directly understood by a microprocessor, and is termed **machine code or machine language**. Every CPU model has its own native machine code or instruction set. The instruction set consists of a limited number of relatively primitive tasks such as adding or subtracting data in specialized memory placeholders called registers, or moving data from one register to the next.

- Despite their enormous processing speed, the intrinsic mathematical capabilities of a microprocessor are quite limited; a CPU cannot perform simple multiplication or division on its own – it has to be taught how to do it. By stringing a series of machine codes together, more complex processing (e.g., multiplication) is possible.

- Both machine code and its symbolic representation (assembly language) are considered as low-level languages because they are the closest command analog to the actual functional details of the microprocessor. Low-level does not imply diminished quality or efficiency; in fact, programs written directly in machine code or assembly language are very efficient.
2.3.4 High-Level Programming Language

- Although low-level programming instructions produce efficient programs, programming in machine code or assembler is difficult, tedious, and very time consuming.
- High-level programming language is really an abstraction of machine code programming because it uses natural language elements instead of arcane numbers and abbreviations. This makes the process of programming simpler, intuitive, and more understandable to the human programmer.
- High-level programming is the foundation of most software development projects. There are many high-level languages in common use today. Some of the languages currently include C, C#, C++, BASIC, Pascal, Java, FORTRAN, COBOL, and others.
- Using high-level programming languages, programmers (or “coders”) type out individual lines of the source code for an application, using a development software program. The lines of the source code need to be translated into machine code before the program can be understood and tested on the microprocessor. This conversion process is known as compiling a program and the software that converts the source code to machine code is known as a compiler.
- Most development software platforms include one or more compilers. The compiler turns the source code into an executable program that is customized for the specific OS/microprocessor combination that the program was developed for.
- The compiler saves the programmer a substantial amount of time and effort by constructing the sequence of machine codes that accurately represents each source code command.
- Programmers must follow a tedious sequence of compiling, testing, identifying errors, correcting errors, re-coding, and re-compiling a program in a process known as debugging the program. The majority of time devoted to programming is spent on debugging the code.
- Scripting languages differ from compiled languages in that the source code is interpreted and converted into machine code at the time of execution – obviating the compiling process. The development process with scripted languages is typically more rapid than with compiled code; however, because scripting languages are interpreted at the time of execution, they are typically slower to execute. Therefore, scripted language is often reserved for smaller programs that are not computationally intensive. Scripting languages include Apple Script, Visual Basic (or VB) script, shell script, and JavaScript.
2.4 Computer Networking

- A **computer network** is a group of two or more interconnected computers that are capable of sharing data and resources. Networking allows multiple independent users to share the same resources (i.e., applications and data) and work with these data simultaneously. Fast, reliable networks form the backbone of digital Radiology department and allow large quantities of imaging data to be efficiently transported between modalities, archives, and viewing stations.

- Computer networks can be classified on the basis of scale (i.e., size, complexity), scope, topology, architecture, and connection method. The most common network is the **local area network (LAN)**. A LAN is characterized by serving computers in a small geographic area such as a home or an office.

- A network that is comprised of two or more LANs is termed a **wide area network (WAN)**. Although the term is somewhat ambiguous, it is more commonly used to describe networks with a broad geographic coverage – metropolitan, regional, or national. The largest WAN is the public Internet, which is a global system of interconnected computer networks.

- A typical Radiology department network would consist of at least one LAN that may be interconnected to a larger WAN (e.g., hospital network).

- Connection of two or more networks (i.e., **Internetworking**) changes the scope of network resources to any computer on the network. An **intranet** is one or more networks that are under control of a single administrative authority. Access to any external or unregulated networks is either not provided or is limited to authorized users.

- An **extranet** is an internally managed network (intranet) that maintains limited connectivity to networks that are neither managed, owned, nor controlled by the same entity. An extranet is typically isolated from the public Internet with security measures such as firewalls that regulate connectivity to outside or unmanaged networks. Most hospitals and business organizations configure their internal network in this way.

- Many home networks (wireless or wired) are extranets that consist of a LAN with access provided to the public Internet (WAN) via an **Internet service provider (ISP)** (e.g., Comcast, AT&T, Verizon, etc.).

### 2.4.1 Physical (Hardware) Networking Components

- Basic physical components of a computer network include the network card, cabling, and a point of connection (e.g., hub, repeater, bridge, router, or network switch).

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**Further Reading 2.8:** Networking

The network interface card (NIC) is the piece of computer hardware that provides the capability for a computer to communicate over a network. Every NIC possesses a unique number, its media access control (MAC) address. This number can be used to help route data to and from other computers.

The physical connection of the computer to the network is usually accomplished through specialized cabling that contains four pairs of simple copper wires (twisted pair) in a configuration known as category 5 or Cat5, or its enhanced version Cat5e. Cat5 cabling frequently terminates in special rectangle plastic connectors that resemble oversized telephone handset connectors.

Other forms of physical connection used less often include fiber optic cables (optical fiber) and wireless (802.11x). Fiber optic provides greater transmission capacity (bandwidth) than Cat5 and wireless affords greater access where physical connections are not readily available.

The term Ethernet describes the wiring and signaling schema for the NIC and the cabling between devices on the network.

2.4.2 Network Switches

The cornerstones of the computer network are switches, the devices that connect other devices together on the network. Switches vary in the degree of functionality by which they manage the data traffic that passes through them. The term switch is an imprecise term that refers to many types of network devices.

The simplest and most inexpensive of network switches is the network hub. The hub provides a simple and passive method for all computers connected to it to transmit and receive data to each other. Each computer network cable has an individual connection (port) to the hub. The hub creates a shared medium where only one computer can successfully transmit at a time and each computer (host) is responsible for the entire communication process.
• The hub is a passive device. The hub merely replicates all messages to all hosts connected to it and does not have any capability to route messages to a specific destination. A network hub is the most basic and inefficient means of connectivity. For this reason, simple hubs are rarely used today.

• The network bridge improves upon the design of the basic network hub by providing a level of active management of the communication between attached hosts. The bridge is capable of learning the MAC addresses of the connected host computers and will only send data destined for a specific host through the port associated with a unique MAC address. By routing the data stream to the intended recipient, switching creates a more efficient method for network transmission.

• Since the bridge needs to examine all data sent through it, it creates some processing overhead that slows the data transmission rate. Bridges typically support data transmission rates of 10, 100, and 1000 megabits per second (Mb/s).

• The network router offers yet another level of technical sophistication over the network bridge. Like the network bridge, a router is capable of examining the contents of the data passing through it and is able to discern the identity of the sender and the recipient. However, instead of relying on the value of the hardware NIC MAC address (which is fixed and not configurable), the router is capable of discerning data based upon a software configurable identifier known as the Internet protocol address (IP address).

• The IP address is a configurable 32-bit numeric value (e.g., 192.123.456.789) that is used to uniquely identify devices and the networks to which they belong. Using this schema, a host that is accessible globally must have a unique IP address; however, a host that is hidden within a private network need not have a globally unique address (it only needs to be unique on the local network). This scheme allows for conservation of unique IP addresses.

• The typical broadband network router used in home networking has additional features such as dynamic host control protocol (DHCP), network address translation (NAT), and a network firewall. These additional features provide a secure connection between the home LAN and the ISP WAN. The router using NAT serves as a proxy that allows multiple computers to share a single public Internet IP address. The broadband network router assigns each computer in the home network its own IP address that is only unique within the home network.

2.4.3 Network Protocols

• In order for them to communicate effectively, each device must adhere to a specific set of rules for communication called network protocols. Networks are usually comprised of a heterogeneous group of devices of different make,
model, vintage, and performance. The most ubiquitous network protocol over Ethernet is the Internet protocol suite (IPS) or transmission control protocol/Internet protocol (TCP/IP).

- TCP/IP is a software abstraction of protocols and services necessary for the establishment of communication between two computers on a network. This network abstraction was set down by the International Organization for Standardization (OSI) and is referred to as the OSI network model. The model describes five to seven information layers that link computer software application to the hardware that must perform the actual transmission and receipt of data.
- The layers in the network OSI model rely upon protocols to regulate how information is passed up through and down the OSI stack.
- The Internet protocol suite defines a number of rules for establishment of communication between computers. In most instances, the connection is a one-to-one relationship. Two computers go through a negotiation process prior to making a connection. The negotiations include request and acceptance of an initial connection, the type of connection, the rate of transmission, data packet size, data acknowledgement as well as when and how to transmit missing data.

### 2.4.4 Data Packets

- Data transmitted over a network is broken up into multiple small discrete chunks or packets before being sent over the network by the NIC. Packet size is variable and is part of the “negotiations” when establishing a network connection with another computer.
- Since a network segment can only be used by a single computer at any one instant and the physical parts of the network (i.e., cabling and switches) are shared by many computers, splitting data streams up into smaller parcels in a shared network model improves network efficiency dramatically.
- Switching and assigning resources on a shared network is a complex process – one which needs to occur in the order of microseconds to maintain efficient communication between thousands of devices that are potentially competing for these resources. Despite the refined sophistication of the system, there are instances where two or more computers attempt to send data along the same segment simultaneously. This phenomenon is termed a collision. Optimum network design mandates minimizing collisions and maximizing collision detection to maintain fidelity of data transmission.
- Additional metadata is automatically married to each data packet based upon protocols specified in by IPS and contains information such as the data type, packet number, total number of packets as well as the IP address of the
sender and receiver. This is analogous to placing a letter (packet) in an envelope with delivery information (sender and return address). Data packets with this additional data wrapper are referred to as data frames.

- Since each frame of transmitted data contains information about where it originated and where it is supposed to go, routers can then examine each packet and forward it through the relevant port that corresponds to the recipient. Moreover, since each packet is self-contained and auto-routable, packets from a single message can travel over completely different routes to arrive at the same destination. Routers instantaneously analyze and balance network traffic and will route packets over segments that are currently under a lighter load.

- At the receiving end, the OSI model also details how to reassemble the individual packets back into the original file. Each packet bears both an identifier and sequential number that specify what part of the original file each packet contains. The destination computer uses this information to re-create the original file. If packets are lost during the transmission process, TCP/IP also has methods for requesting re-transmission of missing or corrupt packets.

- Network bandwidth is defined as the rate at which information can be transmitted per second (bits/s). This can vary tremendously depending upon the type of physical connection, switches, and medium (i.e., cabling versus fiber versus wireless). Theoretical bandwidth of Ethernet, for example, varies from 10 to 1000 Mb/s. Another technology, known as asynchronous transfer mode (ATM) can support bandwidths ranging from 155 Mb/s (OC3), 622 Mb/s (OC12) to 2488 Mb/s (OC48).
• It is important to recognize that there can be a substantial difference between the values of a theoretical bandwidth and actual bandwidth. While packets of data move at the speed of light, other factors such as quality of cabling and efficiency of network switches contribute to network overhead that can impede actual performance.

### 2.5 Client–Server Architecture

• The client–server computing model is one of interdependency between two or more computers where one computer provides data or services to the other.
• Early networks were used primarily to backup data to a central location during off-hours. As technology has continued to evolve, there has been a growing convergence of desktop computing and network computing. In the past, maximizing computing efficiency required application software and data to reside on the client computer. A fat client (thick or rich client) is a host application that performs the bulk of data processing operations for the user with minimal to no reliance on network resources.
• By leveraging the power of faster network services, real-time transfer of data and application resources to the client desktop computer is afforded. The client makes requests from a dedicated, powerful networked host computer (a server) that stands ready to provide application services or data to the client over the network.
• While any computer can be configured to act as a server, most servers have additional hardware capacity to support the increased demands of multiple simultaneous users (i.e., faster multi-core CPUs, large memory stores, and large hard drives).
• This close interrelationship of multiple clients and a server is known as client–server architecture. Almost the entire structure of the Internet is based upon the client–server model. This infrastructure supports delivery of web pages over the World Wide Web and e-mail. The most basic client application is the web browser, which interacts directly with the server to render

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**Definition 2.15: Server–Client**

A server is a computer that provides application services or data. A client is a computer or software application that receives those services and data.

**Key Concept 2.16: Client–Server Architecture**

In its purest form, client–server architecture concentrates on maximizing virtually all of the computational power on the server while minimizing the computational requirements of the client stations. This affords great economies of scale without loss of functionality.
data, images, or advanced visualizations. Any application that is accessed via a web browser over a network that is coded in a browser-supported language (i.e., JavaScript, Active Server Pages – ASP, Java, HTML, etc.) are called web applications or webapps.

- A thin client (lean or slim client) is an application that relies primarily on the server for processing and focuses principally on conveying input and output between the user and the server.
- The term thin-client application is often misused by industry to refer to any function or application that runs within a web browser – however, this is an incomplete definition. Even if the application is used inside of a web browser, if additional software or browser plug-ins are required or local data processing occurs, the term hybrid-client is more appropriate. Most PACS client viewing software that runs within a web browser is classified as hybrid-client.
- Modern PACS systems are designed to leverage this configuration where the majority of the image management is controlled by a powerful central server that responds to multiple simultaneous requests for image data from relatively inexpensive, less-powerful client viewing stations.
- Software applications that are designed to operate principally over a network in a client–server configuration are grouped collectively into something known as web services. There are established profiles and specifications that define how these services are supposed to interoperate with service providers and service requesters. Web services differ from web applications in that web services need not run inside a browser or be constructed with web elements.

### 2.6 Database Applications

- Many useful web services and web applications provide direct access to databases.
- There are a number of database models; however, the relational model is used most often. In the relational model, data are abstracted into tables with rows and columns. Each row is an individual record and each column is a separate attribute or field for each record. One or more tables are linked logically by a common

**Definition 2.17:**

**Thin Client**

A software application that does not depend upon any additional software components and does not perform any processing on the local host.

**Definition 2.18:**

**Database**

A structured collection of data. Data that are housed in a database are more amenable to analysis and organization. Databases are ubiquitous and are the essential component of nearly every computer application that manages information.
attribute (e.g., an order number, serial number, accession number, etc.).

- Databases also support an indexing mechanism that confers greater speed to the system when accessing or updating data. Indexing comes at some cost since it adds some processing overhead to the system.
- The most common programmatic operations on a relational database include reading or selecting records for analysis, adding records, updating records, or deleting records.
- Structured query language (SQL) is a database-specific computer language designed to retrieve and manage data in relational database management systems (RDMS). SQL provides a programmatic interface to databases from virtually any development platform.
- Databases are integral to the infrastructure of most business systems including information systems in Radiology. Virtually, every aspect of Radiology services is tied to relational database functions from patient scheduling to transcription.

Pearls 2.19

- Although the microprocessor is frequently personified as the “brain” of the computer, it has no innate “intelligence” or inherent ability to make decisions. The microprocessor’s strength is in its ability to process instructions and manipulate data at amazing speeds.
- All application software runs on top of the OS that, in turn, is directly integrated to the hardware. In general, application software cannot interact directly with the hardware; all interactions are brokered by the OS.
- A computer that is accessible globally must have a unique IP address; however, a computer that is hidden within a private network need not have a globally unique address (it only needs to be unique on the local network). This scheme allows for conservation of unique IP addresses.
- A thin client (lean or slim client) is an application that relies primarily on the server for processing and focuses principally on conveying input and output between the user and the server.
- Software applications that are designed to operate principally over a network in a client–server configuration are grouped collectively into something known as web services.

Self-Assessment Questions

1. The core hardware components of a digital computer include everything except
   a. Microprocessor
   b. Memory
   c. Bus
   d. Keyboard
   e. Operating system
2. Volatile memory is distinguished from non-volatile memory by
   a. Poorer performance of volatile memory
   b. Flammability of volatile memory
   c. Inability of volatile memory to retain data with power loss
   d. Greater expense of volatile memory
   e. None of the above

3. Which is not true about storage?
   a. On-line storage is readily available
   b. Near-line storage requires human intervention
   c. Off-line storage is not accessible by robotic devices
   d. Data are stored on media such as tape, compact disk or DVD
   e. None of the above

4. Which is the best statement regarding the motherboard data bus?
   a. It connects to the keyboard
   b. It connects to the power supply
   c. It interconnects the components on the motherboard
   d. It connects to the disk drive
   e. None of the above

5. What is the fundamental distinction between software and hardware?
   a. Price
   b. Hardware is a physical entity
   c. Packaging
   d. Complexity
   e. None of the above

6. The purpose of the operating system (OS) is
   a. To manage memory allocations
   b. To copy files to disk
   c. To manage the user interface
   d. To manage computer resources
   e. All of the above

7. Computer drivers are
   a. Names for a specific type of golf club
   b. Large programs that take control of the OS
   c. Small programs that provide a bridge or interface between hardware and software
   d. Similar to computer viruses
   e. None of the above

8. Low-level programming languages are (best answer possible)
a. Fairly simple to learn and use
b. Are primarily used by human computer programmers to create applications
c. Are not as costly as high-level programming languages
d. Are used primarily by the CPU
e. All of the above

9. The most complex network switch is the
   a. Network hub
   b. Network router
   c. Network bridge
   d. They are all similar in complexity
   e. Not listed

10. Which is true of thin-client applications?
    a. They require a web browser to run
    b. They do not need additional software
    c. They require a networked server
    d. They require an internal database
    e. All of the above
Chapter 3
Introduction to PACS

Matthew D. Ralston and Robert M. Coleman

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3.1 Introduction: Rationale and Goals for PACS

Picture archiving and communications systems (PACS) represent the technological core of a modern, digital, radiology department. Although their core function is storage, distribution, and display of medical images, they have taken on an increasingly important role in the entire workflow of the radiology department. A PACS ideally replaces all stand-alone, single-modality
workstations. PACS is further strengthened by integration with a hospital’s other IT infrastructures, including the hospital information system (HIS) and radiology information system (RIS).

Modern PACS are complex and require skilled and dedicated personnel for proper setup and ongoing functionality. PACS is a relatively expensive undertaking both for the required system hardware and support and for the required support staff. It is fundamentally different from traditional radiology purchases, like CT or MRI scanners, in that it does not result in additional income for radiology. PACS must therefore pay for itself in cost savings from the reduced need to produce, store, and handle film and by reducing the likelihood of preventable medical errors, which is a harder cost to quantify.

Carefully designed PACS assure accurate identification of patient, exam, and associated clinical data required by the radiologist and others, in support of the workflow performed within the radiology department (Figs. 3.1 and 3.2).

**Definition 3.1: PACS**
A picture archiving and communication system stores, distributes, and displays medical images for interpretation or review.

**Definition 3.2: Wet Read**
A brief preliminary interpretation rendered by the radiologist before taking the time to formally and completely review the images. In the film era, this report was rendered while the film was still wet from processing.

**Key Concept 3.3: Web-Based Access**
The most cost-effective means of distributing images and reports is via a web-based product, off-the-shelf PCs, and wide area networks that are already in place. Clinicians have overcome their historic aversion to computer technology and are increasingly expecting their patients’ studies and reports to be available within the Electronic Medical Record (EMR) of the hospital. If a radiology department fails to provide good web access, with a relatively deep archive, in a reliable and accessible system, then the department should expect clinicians to demand more costly service, such as their own workstations, printed films, or a never-ending stream of CDROMs. It behooves a radiology department to get in front of this issue, and break down any barriers that exist on the web-access solution.

**Synonyms 3.4**
- Clinicians
- Nonradiologist physicians
- Referring doctors
3 Introduction to PACS

3.2 Core Components of a Modern Digital Radiology Department

3.2.1 Radiology Information System

- RIS is the tool that most technologists and radiology administrators use for their daily activities.
- Multiple vendor choices.
- May be bundled with other Hospital Information Systems.
Must be able to seamlessly receive ordering information from HIS.
Must allow radiology personnel to enter and alter orders.
Uses Health Level 7 (HL7) as its core communication protocol.

**Definition 3.5: RIS**
The Radiology Information System is software that manages the day-to-day operations of a radiology department, or group of cooperating radiology departments. Can receive orders from the hospital information system, or allow manual input of orders locally. Messages outbound to PACS broker use HL7 format.

### 3.2.2 PACS Core
- **Archive** of DICOM data from modalities
  - Ideally redundant.
• PACS Database
  – Supports powerful patient-search and study-matching tools.

• Networking equipment
  – Usually 1 or 10 Gb at the core and between large nodes of the enterprise.
  – Minimum 100 Mb to the individual PACS workstations.
  – Ideally **segregate PACS data traffic** from other enterprise data traffic for performance and reliability, but route traffic between networks as needed.

• Software for **distribution of images** to clinicians
  – May be web-based or web-deployable
  – May be integrated with an enterprise EMR
  – May be part of core PACS or a free-standing system.

### 3.2.3 PACS Broker

• PACS work best when the strongest aspects of the organizational powers of the RIS are combined with the database and archive access tools of PACS.
  – This requires a “broker” to translate and interconnect the HIS/RIS (which generally uses HL7 messaging) with the imaging portion of the PACS, which communicates via the DICOM protocol.
  – The broker will generally provide **DIC OM capabilities** (for example, DICOM modality worklist) to components within the PACS network that use DICOM.

• While some PACS may claim to be “brokerless,” they are simply embedding the functionality generally performed by the broker into other parts of the PACS.

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**Definition 3.6: DICOM**

Digital Imaging and Communication in Medicine is the standard format for PACS files and messages.

**Definition 3.7: Modality**

May refer to a specific machine that acquires images (e.g., CT scanner #3), or a class of machines that use the same basic technology (e.g., modality = CT).

**Definition 3.8: PACS Database**

For PACS, the pertinent data elements included in the database are the patient demographics, associated reports, study description, where the images were obtained, and where the images are stored.

**Definition 3.9: PACS Broker**

Software that converts and translates between HL7 messages (for the HIS or RIS) and DICOM transactions (for the PACS).
While not explicitly called a “broker,” these systems contain hardware and software that do what is traditionally referred to as a “broker.”

### 3.2.4 Diagnostic Workstations

- Radiology workflow has changed.
  - The modern radiologist no longer works in front of fluorescent light-boxes, viewing transparency images.
  - The current workflow is accessed by the radiologist at a high-performance computer, commonly called the diagnostic workstation.
  - The diagnostic workstation may be a generic DICOM viewer, or a proprietary system offered by the PACS vendor, or may have features of both architectures.

- The workstation is the user interface that allows the desired functionality to occur (outlined below).
  - It is usually comprised of a high-performance personal computer with high-resolution, high-brightness monitors.
  - It holds and operates the study retrieval and study viewing software.
  - The local PACS workstation is linked by standard networking to the PACS core and archive.

- As opposed to early point-to-point networking systems, most modern PACS do not attempt to automatically route entire studies (and needed comparison studies) to individual workstations before the radiologist needs them. Usually, all the images of the exam and the comparison studies reside in the PACS core and are only temporarily retrieved to the PACS workstation for review.

- **Functions** of PACS workstation for the radiologist:
  - Allows assembly of sets of cases to be sorted and identified (i.e., worklists) so that individual radiologists can pull their respective workload from the overall archive.
  - Facilitates retrieval of new studies to be read from the PACS core to local memory or the local hard drive.

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**Key Concept 3.10: Connectivity**

PACS workstations maintain separate, direct links to the PACS database and to the PACS archive. This reduces the routing path for data and improves performance.

**Key Concept 3.11: Worklists**

Each PACS user needs to see a list of patients that is pertinent to his or her own workflow. Intelligent filtering and ordering are needed to make these worklists useful.
– Communicates with the PACS core to identify, retrieve, or prefetch the pertinent comparison studies that the radiologist is most likely to need.
– Allows viewing new and old exams.
– Facilitates retrieval and semi-automated display of available prior studies.
– Image manipulation software tools operated via an intuitive GUI.
– Commonly linked to dictation/reporting tools.
– Changes the status of studies to prevent multiple radiologists from trying to dictate the same case.
– Allows all radiologists to be aware of what is waiting to be reported.

3.2.5 Nonradiologist Access to Radiology Studies and Reports

- While the PACS communications functions within radiology are commonly carried out using dedicated, high-speed networks, clinician viewers of studies and reports are commonly located outside the core hospital local area network (LAN) and are reliant on slower connections.
- Since clinicians no longer have access to films or printed reports, it is essential that clinical services have ready access to images and reports, wherever they may be.
- Large data sets from PACS would bog down in many WAN environments, and for that reason, data compression is commonly utilized for clinical review purposes.
  - Compression allows clinicians to view large image sets from remote locations with relatively low-speed network connections.
  - Lossless compression (typically used within the PACS core) results in no image degradation, but only allows compression rates of about 2.5:1.
  - Lossy compression, however, may result in a significant compression ratio (10:1 or more), but may result in some image quality loss.
  - Lossy compression is recommended for performance only when the images will NOT be used for primary interpretation.

**Definition 3.12: Master Patient Index**

The MPI, also known as the Enterprise Patient Index (EPI) is a multi-institutional database that allows reliable identification of a patient, as well as access to other identities the patient may have at other sites. Allows exams from multiple sites to coexist in a single PACS.
3.3 Core Workflow Elements to be Supported by PACS and the Informatics Team

- Capturing DICOM studies.
  - Digital modalities, using standardized DICOM protocol, capture digital data.
  - Examples include computed tomography, magnetic resonance imaging, positron emission tomography, computed radiography, direct digital radiography, digital fluoroscopy, angiography, ultrasound, digital mammography, nuclear medicine, mobile C-arm fluoroscopy.
- **Validating** and confirming DICOM data versus the HL7 order using the PACS broker.
- **Storing** studies using industry-standard processes generally accepted by IT (e.g., RAID, SAN, NAS).
- Allowing retrieval and display of current exam by radiologists via PACS diagnostic workstations.
- Allowing retrieval of images and reports by clinicians via PACS clinical workstations, or PCs running web-based applications.
- Automated retrieval and display of pertinent prior studies using predefined “pertinent prior” and “prefetch” rules.
  - Using the power of the PACS database and operating software to retrieve and transmit comparison studies from near-term archive and long-term archive.
- Prevent more than one radiologist from reading a particular study.
  - Once a radiologist starts a dictation, instant notification is transmitted back to the core, triggering that case to be hidden from other radiologists seeking new cases to read.
- Support generation and storage of printed reports:
  - Traditional dictation and transcription
  - Speech recognition
  - Standardized reports
  - Structured reporting
  - Trainee reporting

**Definitions 3.14: Residents and Attendings**

Apprentice radiologists, having completed medical school and now specializing in radiology, are generically called “trainees” or “housestaff.” They are divided into residents (more junior) and fellows (more senior). The interpretations rendered by trainees must be overseen by board-certified (“attending” or “staff”) radiologists.

- **Support PACS users**

Radiologists, technologists, and clinicians should be considered the core **customer base** of PACS. If these three groups are satisfied, then the PACS is a success, as long as nothing in PACS negatively impacts other systems such that other critical departmental functions (e.g., radiology scheduling, reporting, and billing) are degraded.

**Further Reading 3.15:**

**Customer Base**
- Chapter 11 focuses on interactions with the many customers who depend upon the PACS.
Radiologists access studies from dedicated diagnostic workstation requiring tools for manipulating images, retrieving and comparing prior studies, and rendering formal reports.

Technologists interact with PACS primarily as storage devices, but can also use the PACS as a means for end-of-shift quality assurance, assuring that all desired studies have reached the radiologists and the clinicians.

Clinicians may receive images and reports in one or more of several means.
- Clinical review stations.
- PC-based review on general-purpose, multiusage PCs. Usually, utilizing some sort of web transmission protocol, a compact viewing applet, and data compression to speed functionality.
- Creating CD-ROMs of patient exams (“burning a CD”). The CD includes a viewing application, and a file of the images from the study. May use DICOM format, JPEG, or vendor-specific proprietary file type.
- Printing traditional film copies and paper reports (this is very expensive).

3.4 New Professional Roles Necessitated by PACS

PACS and RIS are available from dozens of vendors, but the field of medical imaging is regulated in a fairly legalistic language by the ACR. Due to standardization, most PACS wind up possessing, operating, and supporting certain stereotypical types of hardware, software, databases, and archives. Likewise, clinical demands and workflow expectations are fairly uniform across modern medicine in the developed world. As a result, the number and types of new tasks and professional opportunities tend to fall into a few, well-defined categories, regardless of which PACS vendor is chosen. (Obviously, at a smaller site, one individual may have two or more of the following responsibilities.) The title of Imaging Informatics Professional encompasses all of these roles.

Further Reading 3.16: Quality Assurance
- Chapter 13 focuses on quality control throughout the radiology department.

Further Reading 3.17: Radiology Regulations
3.4.1 PACS Administrator

Often the first individual identified to support a PACS is the PACS administrator.

- The PACS admin is responsible for the day-to-day operation of the PACS.
- Understands the intricate nuances of the radiology workflow.
- Knows how to use the PACS to ensure that workflow is optimal for all users.
- Takes care of the basic functions of a PACS (transmission, display, and archive).
- Fixes errors that occur throughout the normal workflow, whether they are caused by human or system error.

**Key Concept 3.18: Important Skills for Maintaining PACS**

- Communication – With all stakeholders, say it “eight times eight ways”
- Vendor relationships – Knowing when to demand and when to accept
- Planning – Capacity, upgrades, disaster recover, business continuity
- Project management – the PACS is a never ending project
- Customer service – Clear, concise, patient, friendly, and empathetic yet firm
- Financial management – An insatiable need for funding

3.4.2 Image Service Representatives

A less obvious role created when a PACS is implemented is the image service representative (ISR).

- Commonly the personnel formerly thought of as “film librarians.”
- One common assumption is that the implementation of PACS eliminates the need for staff to “manage films.”
- However, with the coming of PACS, the role of the traditional film librarian is greatly enhanced, not eliminated.
- ISRs perform much of the same functions as they did in the film world, such as
  - locate exams
  - track studies
  - provide images to patients and physicians requesting access
  - ensure all data necessary for the accurate interpretation of an exam are provided for the radiologist.

3.4.3 PACS Systems Analyst

If the PACS administration manages the “front end” of the PACS application, the PACS systems analyst manages the “back end.”
• Respond to system issues with fall outside the scope of normal day-to-day operation issues.
• Will work very closely with the vendor of the PACS to solve significant system problems.
• Generally, understand the PACS application at a level much deeper than that of the typical users or ISRs. Knowledge base generally needed:
  – Database schemata
  – Networking
  – Report building
  – Script development
  – Application development

3.4.4 Clinical Outreach and User Training

• Coordinate with users inside and outside the host PACS facility.
  – Advice on networking and firewall access.
  – User training for radiologists and nonradiologists.

3.5 Value-Added Adjuncts to the Practice of Radiology, Made Possible by PACS

Once the core functionality and reliability of a PACS has been achieved, it is possible to “add on” functionalities to the PACS workstation environment. Some of these functions were handled with paper forms and faxes in the past or were frankly avoided due to their complexity and the labor involved in the predigital era. PACS and the supporting digital infrastructure allow new tools for improving the quality and efficiency of the radiologists and the radiology department, some of which were simply never practical before.

3.5.1 Programmed Peer Review

• Allows randomized double readings of studies to assure quality of readings.
• Automated feedback to the original radiologist.
• Allows department chair to objectively document the performance of the radiologists in generating accurate reports in the proper format, etc.

Key Concept 3.19: Peer Review
Peer Review is a formal process for reviewing the work of a fellow physician in a confidential, nonthreatening, and nonlegally discoverable manner to provide feedback in a protected manner. The goal is to let a fellow physician know about suggestions for improvement in a tactful, productive, and respectful manner.
3.5.2 Asynchronous Communication Tools

- **Over-reading.**
- Remote feedback and teaching of radiology residents.
- Communications with referring physicians, such as the emergency department.
- Can be autolinked to existing email programs (assuming HIPAA-secure email protections).

**Definition 3.20: Over-reading**
Radiology trainees (residents) need and deserve feedback on the preliminary readings they provide when staff (attending radiologist) is not present, commonly overnight or weekend situations. This can be provided by attending physically sitting down with the resident, but this is sometimes impractical. PACS allows the attending to review or “over-read” the on-call exam and the attached reading and to provide “grading” and feedback, using mechanism similar to peer review.

3.5.3 Integration of Nighthawk Wet Readings

- If there has been any type of preliminary reading provided by a resident or a remote teleradiology overnight service, it is mandatory that the individual rendering the final, official report has access to what was communicated overnight.
- Similar to peer review, the reading radiologist should be able to give feedback or “a grade” to the person providing the wet reading. This can be handled from PACS, if set up correctly, allowing the radiologist to render this feedback efficiently.

**Definition 3.21: Nighthawk**
Generic term indicating preliminary or final interpretations provided on overnight and weekend cases. The “nighthawk radiologist” is usually located in a different time zone and uses networking to get images to read within a few minutes and faxing out preliminary reports to radiology departments and emergency departments. This function is widely used by most hospitals in the United States, particularly those that are too small to have radiologists provide 24 × 7 onsite service.
3.5.4 Electronic Teaching Files

- Teaching centers want to have “canned” cases of known pathology, with captured images and associated documents, for teaching trainees. This has traditionally been done with film and film folders, but this is best replaced by a digital process.

3.5.5 Regional Sharing of PACS Functionality: Shared Archive

- “Nothing makes a radiologist smarter than having the old study of the same body part for comparison.” This holds true for in-house studies from the same institution. It also holds true for studies from other regional institutions.

3.5.6 Advanced Visualization Technologies

(Impossible without workstations and ideally integrated into the PACS diagnostic workstation.)

- Three-dimensional and multiplanar reformats of CT and MRI data
- Overlay and synchronization of CT and PET data (“PET fusion”)
- CT perfusion and MRI perfusion
- Coronary CT angiography
- Virtual colonoscopy or CT colonography
- Advanced MRI techniques
- CT angiography of all body parts
- MR angiography of all body parts

3.5.7 Site-to-Site Transfer of DICOM Exams

Once PACS is in place at many sites in a region, image data can be transmitted between disparate PACS. This is technically outside of the PACS infrastructure, but can be partially integrated and can be made automated, or, at least, semi-automated. This should help limit the need to transport and import outside CDs.

Further Reading 3.22: Teaching Files

Pearls 3.23

- The essential elements of PACS include the archive, the database, the broker, the network infrastructure, and the distribution software.
- There are many key workflow steps, inside and outside of radiology, that need to be specifically supported by the PACS software.
- Much of the value of PACS relies on its ability to expand with other software to add value to the medical enterprise.
- The size of the enterprise determines the number of imaging informatics professionals needed to support the PACS.
- IIP functions such as PACS administrator, PACS system analyst, and image service representative may be handled by one individual, a small team, or a large department.

Self-Assessment Questions

1. The primary functions of PACS include image transmission, display, and __________?
   a. Archiving
   b. Manipulation
   c. Registration
   d. Compression

2. The typical radiology technologist is most likely to interact with which of the following systems throughout their workday?
   a. PACS broker
   b. PACS web viewer
   c. PACS diagnostic workstation
   d. Radiology information system

3. Which component of the PACS typically communicates with both the HL7 and DICOM protocols?
   a. PACS broker
   b. PACS database
   c. PACS diagnostic workstation
   d. Master patient index

4. The primary data protocol for transmitting medical images between modalities is
   a. HL7
   b. DICOM
   c. IHE
   d. HIPAA
5. Who is the most likely person to deal with managing the day-to-day operations of the PACS?
   a. PACS system analyst
   b. Imaging service representative
   c. PACS administrator
   d. PACS clinical outreach coordinator

6. A diagnostic workstation used by a radiologist generally offers what feature(s) over a “standard” PC used for clinical review of images:
   a. Higher quality and higher brightness monitors
   b. Faster network connection back to the PACS core
   c. Presence of more advanced image manipulation tools
   d. All of the above

7. Integration of clinical information systems and PACS may result in
   a. An increase in accurate relevant clinical information available to radiologists
   b. Faster turnaround times of results to clinicians
   c. Richer information by the concurrent delivery of images and their associated report
   d. All of the above

8. Which of the following enhancements, if added to a PACS, would enable an attending radiologist to check the work of a resident?
   a. Programmed peer review
   b. Integration of nighthawk “wet” readings
   c. Over-reading
   d. Electronic teaching files
Chapter 4
Modalities and Data Acquisition

J. Anthony Seibert

4.1 Introduction

Acquisition modalities are the image engines in a picture archiving and communications system (PACS). Of the modality mix, radiography comprises approximately 60–70% of all studies performed in a diagnostic radiology department. Since analog screen-film recording technology is still being used in many hospitals and clinics, the implementation of a PACS for electronic image acquisition, display, and archiving is associated with the conversion of analog to digital radiography technology. But the imaging modalities are much more than radiography. Real-time digital fluoroscopy, interventional angiography, and cardiology studies are producing hundreds to thousands of images per examination. Cross-sectional imaging acquisition systems such as computed tomography (CT), magnetic resonance imaging (MRI), ultrasound (US), single-photon emission computed tomography (SPECT), and positron-emission computed tomography (PET) are expanding rapidly and are in many
cases becoming the examinations of choice over projection imaging. The latter issue can have a significant impact on the amount of digital data that must be displayed and archived. For future consideration are the realities of visible light objects from pathology and dermatology, which are potentially orders of magnitude greater in terms of image size, number of images, and impact on the PACS infrastructure. The one common piece is the PACS itself, a crucial, mission-critical system containing patient image data, software, and hardware to deliver information where and when it is needed. As any system is only as good as its weakest link, the image acquisition device configuration management, verification of baseline image performance, and the ability to provide consistent imaging performance and deliver the expected and needed information are essential. The purpose of this chapter is to briefly describe the attributes of acquisition devices in diagnostic radiology, discuss the basic issues and themes common to all imaging modalities, and explore the unique attributes and considerations of each modality for optimizing performance and image quality. Troubleshooting and quality control recommendations are also considered.

4.2 Acquisition Devices in Diagnostic Radiology

4.2.1 Digital Radiography and Digital Mammography Projection Imaging

- **Computed radiography (CR)** is largely cassette based, and as a direct replacement for screen-film, can use existing radiographic equipment. This technology is also known as photostimulable storage phosphor (PSP) radiography.

- **Direct or digital radiography (DR)** is typically assumed to have an integrated detector and X-ray tube/generator system and does not require direct user interaction or handling to acquire and/or display images. Various technologies include optically coupled CCD camera systems, slot-scan detectors, and thin-film transistor (TFT) flat-panel detectors.

- Digital radiography image size depends on detector element dimension (0.2–0.1 mm), field of view, and the resolution of the system.

**Definition 4.1: Radiography**

This imaging procedure uses a uniform beam of X-rays incident on the patient, which are modulated by the tissues, and subsequently detected and converted into a two-dimensional grayscale image by the X-ray detector. Benefits include a rapid and inexpensive acquisition capability; difficulties include super-imposition of anatomy that can hide findings or mimic disease processes.
view (FOV) of 18 × 24 cm to 35 × 43 cm, and bit depth of 10–14 bits/pixel. This translates into typical image sizes of 8–32 MB for individual projection images.

- New adaptations of DR devices take advantage of the high-speed acquisition capabilities to produce alternate image processing schemes, such as dual-energy radiography and digital tomosynthesis.
- Capture of kV, mA, exposure time in the DICOM metadata assist radiation dose assessment and problem solving.
- Digital mammography is an X-ray projection imaging procedure specifically used for imaging the breast. Dedicated X-ray systems are used in conjunction with digital detectors (1) CR as a direct replacement for screen-film, which can be used with existing acquisition systems; (2) flat-panel DR, which is integrated with the X-ray and generator system.
- Digital mammography image size ranges from 0.1 to 0.05 mm detector element size and 12–16 bits of data per pixel to produce image sizes of 8–50 MB for 18 × 24 and 24 × 30 cm FOV.

**Key Concept 4.2: DR Exposure Latitude**

CR and DR can capture a large range of transmitted exposures (wide exposure latitude) allowing for under and overexposures. The exposure index is a manufacturer generated number that indicates the “speed class” of the digital detector for a given examination, which should be used as an indication of the proper exposure to the patient (and to the detector). Optimization requires system calibration and technologist training to identify and adjust to situations where the exposure is too high or too low.

**Thought Problem 4.3: Computed Radiography (CR) or Digital Radiography (DR)?**

Which to choose? The answer depends on the needed throughput, types of studies to be performed, flexibility of positioning, and existing infrastructure. For positioning flexibility, a cassette-based detector system, CR, is superior; higher patient throughput is achieved by a DR system.

**Further Reading 4.4: CR Versus DR**

Our Experience 4.5: Early Deployment of CR

In July 1998, the University of California Davis Medical Center replaced all screen-film detectors with CR. Initial repeat rates went from 8 to 10% to below 1% due to the scaling of images for under or overexposure. Many nondiagnostic images were due to underexposure and quantum mottle, resulting in increased technique factors, much more than necessary. The higher (over) exposures were not easily identified since images appeared with high image quality, resulting in a patient dose greater than necessary, noted as “dose-creep.” A QC program to monitor exposure trends through the digital “exposure index” was implemented to recognize and avoid overexposures and to train technologists on digital radiography exposure index values to verify “proper” radiographic technique and image quality (see Seibert, JA, et al., Computed radiography x-ray exposure trends, Acad Radiol 3(4): 313–8, 1996). Even 10 years later (2008), constant diligence is required for keeping repeat rates low and to remind technologists of proper radiographic techniques for ensuring high image quality and safe patient care.

Key Lessons Learned

- Technologist complacency is fostered by the internal scaling capability of digital radiography and can lead to “dose creep” and hidden overexposures.
- A program to monitor exposure indices should be implemented for feedback.
- Exposure index value knowledge and compensation methods for under or overexposure must be part of technologist training.
- Proper calibration of automatic exposure control phototimer systems is crucial.

Specific laws of the Mammography Quality Standards Act (MQSA) govern the implementation of digital mammography systems, display workstations (e.g., 5 MPixel [2500 × 2000] matrix) and quality control procedures.

For computer-aided detection (CAD) algorithms often used with digital mammography images, “for processing” (raw) image data is necessary.

Further Reading 4.6: Mammographic Image Quality

- Practice guideline for digital radiography.
- Practice guideline for determinants of image quality in digital mammography.

4.2.2 Digital Fluoroscopy and Interventional Radiology

- X-ray image video sequences of 1 up to 60 frames/s are acquired for viewing and evaluating patient anatomy.

**Definition 4.7: Fluoroscopy**
A “real-time” X-ray projection image acquisition sequence used for dynamic evaluation of many patient procedures in diagnostic and interventional radiology.

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**Key Concept 4.8: Fluoroscopy and Fluorography Image Acquisition Modes**

- **Continuous fluoroscopy** uses a very low constant X-ray tube current while the fluoro pedal is depressed.
- **Pulsed fluoroscopy** uses high-tube current with short pulses synchronized with the video-frame rate. Typical rates are 15, 7.5, 3.75 frames/seconds.
- **Digital fluorography “photospot images”** use much higher X-ray intensity (mA), on the order of 10–100 times larger per frame than conventional fluoroscopy to produce images of low-quantum noise and higher resolution.
- **“Spot radiographs”** use the highest dose and achieve the highest contrast and spatial resolution by employing cassette-based CR detectors in the cassette carriage.
- **Digital subtraction angiography (DSA)** uses temporal subtraction to eliminate stationary anatomy and enhance iodinated contrast displacing blood; sensitivity of dramatically increased to allow lower injected contrast volume.
- **Rotational angiography** acquires images during rotation of the source–detector around the patient. Projection images can be played back in real time, or data can be reconstructed to produce tomographic slices of the patient volume.

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- X-ray detectors: image intensifier/TV or digital flat-panel detectors function at real time (~30 frames/s) data acquisition rates.
- **Typical image sizes** range from $512 \times 512 \times 8$ bit up to $1024 \times 1024 \times 12$ bit. For spot imaging applications, $2048 \times 2048 \times 12$ bit matrices are often used.
- Image sequence with up to several hundred images are produced that can be stored individually or as video sequences (e.g., avi or mpeg files).
- **Archiving?** Real-time fluoro sequences, typically no; digital spot images and DSA, typically yes, but usually a subset of the pertinent images.
- **Legacy equipment** interfacing requires third-party DICOM interface box to capture and encapsulate images for archiving.
• Radiation dose detection and information: Kerma Area Product (KAP) and “point air kerma” measurement devices provide radiation dose details for an examination in the DICOM image metadata.

4.2.3 Computed Tomography (CT)

• Cross-sectional images are created from the acquisition and reconstruction of X-ray “fan-beam” and “cone-beam” projection data collected about the patient in a CT gantry, containing a high-power X-ray tube, collimators, and a linear array of detectors that can rotate at >2 revolutions per second (<0.5 s rotation).

Definition 4.9: Legacy Device
Old equipment purchased before new standards were widespread. Often requires upgraded interfaces to communicate with modern PACS.

Definition 4.10: Computed Tomography
An X-ray imaging procedure acquires thin-slice projection data using a rotating X-ray tube and detector array, and then produces many tomographic images of the anatomical volume by computer reconstruction algorithms.

Key Concept 4.11: CT Numbers
Also known as “Hounsfield Units” or HU, the CT numbers indicate the X-ray attenuation characteristics of the tissues, and range from –1000 (air) to 0 (water) to +3000 (dense bone). CT numbers assist in the identification of tissue composition; for example, fatty tissues have a slightly negative CT# (–10 to –100), while muscle has slightly positive CT# (0 to > +100).

• Data are collected and stored in a “sinogram” storage matrix, from which the CT system reconstructs tomographic slices by a “filtered back-projection” algorithm. “Filters” for reconstructions define the emphasis of image contrast: (e.g., a “soft-tissue”) versus spatial resolution (e.g., a “bone” or “detail”) filter.

• CT preset window width (WW)/window level (WL) settings for anatomical display provides instantaneous translation of image grayscale on the display. WW determines the range of grayscale values portrayed, where a larger number provides a wide latitude, low-contrast appearance, e.g., appropriate for bone. The WL is the average brightness setting of the grayscale values.
  – Abdominal: 400/40
  – Bone: 2000/300
  – Brain: 80/35
Liver: 200/50
Lung: 1500/–700

- **Reconstructed image size** for axial images is most commonly 512 × 512 × 12 bits.
- “Scout,” “topogram,” and “scanogram” are common names for projection images acquired with the detector gantry stationary and the table incremented. These images are used for planning the volume of data acquisition by the technologist and indicate slice location for the radiologist.
- **Spatial resolution** is typically dependent on the slice thickness (z-axis dimension, from ~0.5 to 10 mm) and the reconstructed FOV (x–y plane dimensions, from ~0.2 to 1.0 mm).
- **Contrast resolution** is chiefly dependent on the number of X-ray photons per voxel (volume element = pixel dimensions × slice thickness dimension), and the X-ray technique (radiation dose). A tradeoff of spatial and contrast resolution with dose (image quality versus noise) is always a consideration.
- **Multidetector row** CT scanners acquire multiple slices per X-ray tube rotation, with 16, 64, 128, 256, and up to 320 simultaneous slice acquisitions.
- **CT acquisition techniques** (kV, mA, time, slice thickness, etc.) depend on patient size (e.g., pediatric versus adult) and type of study (e.g., screening versus diagnostic, head versus body).
- Thin-slice datasets comprise 500+ images, up to 2500+ per study; some of the largest studies include CT angiography, cardiac CT (functional evaluation, coronary anatomy, calcification), and perfusion/diffusion studies.
- **Study splitting** for overlapping studies such as chest, abdomen, and pelvis is important for assigning specific accession numbers associated with the exams and delivering only the pertinent information. On older CT equipment, this software is not typically available and requires a third-party solution.

**Pearl 4.12: Data Explosion in CT**

Large CT datasets are becoming commonplace. Analysis by Dr. Richard Morin of the Mayo Clinic Jacksonville demonstrates the need for a paradigm shift for reviewing the examination in an effective manner. If a radiologist takes a minimum one second look at each axial image of 80,000 presented during the day (not an atypical number), then over 22 hours will be required just to look at the images, without even taking the time to dictate the findings! Clearly alternate forms of viewing (e.g., multiplanar and volume reformatted data) are crucial to efficient use of time by radiologists for diagnoses.
“Enhanced CT IOD” provides updated and required elements and tags for new scanner characteristics such as pitch, modulated mA, and dose data.

**Definition 4.13: IOD**

A DICOM Information Object Definition is an idealized functional representation of a real-world object. It often contains more attributes than the real-world object it represents.

**Further Reading 4.14: IOD**

- Digital Imaging and Communications in Medicine (DICOM) standard. DICOM standard documents can be retrieved at ftp://medical.nema.org/medical/dicom/2008. Of particular interest for this chapter is Part 3: Information Object Definitions, downloadable as 08_03pu.pdf.

### 4.2.4 Magnetic Resonance Imaging (MRI) and Spectroscopy (MRS)

- **T1, T2, proton density, blood flow, perfusion, and diffusion** are tissue characteristics exploited by MRI to manipulate tissue contrast.
- **Pulse sequences** are specific timing methods used for applying RF excitation and magnetic field gradients to achieve desired image contrast and anatomical presentation. Spin echo, fast spin echo, inversion recovery, STIR, FLAIR, gradient recalled echo, echo-planar imaging, and many other pulse sequences are used for diagnostic requirements.
- **User parameters** include TR (repetition time), TE (echo time), TI (inversion time), flip angle, and slice thickness (among others).
- Multiple acquisition protocols are common and produce several image sequences for T1 and T2 contrast, perfusion, diffusion, functional, and angiographic (vascular) evaluations.

**Definition 4.15: MRI**

Magnetic resonance is an imaging procedure that uses a strong magnetic field (1.5–3 Tesla) to magnetize protons in the tissues of the body. Radio frequency excitation of the protons results in energy absorption and subsequent re-emission of RF signals, which are detected and processed to reveal the magnetic characteristics of tissues in terms of a grayscale image. Pulse sequences specifically generate tissue contrast differences; typically, several sequences are acquired for a specific MRI study.
- **Contrast enhanced (CE) MRI** data acquisition exploits magnetization properties of gadolinium to change tissue contrast based on T1 and T2.
- **Image sizes** vary widely, more than any other modality, with square and non-square matrix formats (e.g., 64 × 64, 64 × 128, 128 × 128, 128 × 192, 256 × 512, 512 × 512, 512 × 1024...).
- **MR spectroscopy (MRS)** analyzes intrinsic tissue characteristics of metabolites in single or multiple voxels (volume elements). This is a method to noninvasive “biopsy” indeterminate tissue areas in the MR image. Data storage to PACS requires vendor-specific solutions for spectroscopy data. An IOD for MR spectroscopy is defined in the DICOM standard.
- **MR safety training** is required for hospital personnel working in the vicinity of MRI systems, including PACS and informatics specialists. Effects of strong magnetic fields, fringe fields, RF excitation, heating, and dangers of ferromagnetic materials and many other aspects must be known for safety of personnel and patients. See [http://www.mrisafety.com](http://www.mrisafety.com) for up-to-date information on important facts regarding MRI safety.
- **Artifacts** are prevalent with MRI. Radiofrequency (RF) emissions can cause artifacts in the MR images. Care must be taken to ensure proper shielding of PACS networking and other electronic equipment. A *Faraday cage* (copper mesh/plate) encloses the MR room to create an environment that is free of extraneous RF signals.

**Pearl 4.16: Assessing MRI Data Acquisition Sequences and Impact on PACS Storage**

One example of the data generated for breast MRI can reveal the large number of sequences and significant amounts of data that are generated for what might be perceived as a “small” study:

1. 3 plane localizer, 40 images
2. Axial STIR, 50 images
3. Axial T1 FSE, 100 images
4. Axial precontrast, 200 images
5. Axial postcontrast 1, 200 images
6. Axial postcontrast 2, 200 images
7. Axial postcontrast 3, 200 images
8. Subtracted CAD 1, 200 images
9. Subtracted CAD 2, 200 images
10. Coronal MPR, 150 images
11. Sagittal reconstructions, 150 images
12. Various screen captures, 20 images

A significant number of sequences and images result in an average of ~300 MB of data storage per study.
### 4.2.5 Ultrasound

- **Mechanical, nonionizing** radiation is produced with **transducers** operating at frequencies from 2 to 10 MHz to measure acoustic tissue properties.
- **Array transducers** (128–512 individual transmit/receive crystals) produce directional pulses in the tissues and receive returning echoes generated at tissue boundaries. Echo intensities characteristic of tissue properties are converted to variations in image brightness (grayscale) to produce sector or rectangular tomographic slices of the patient.

- **Image size**
  - typical grayscale images: $512 \times 512 \times 8$ bits or $640 \times 480 \times 8$ bits
  - color images: same matrix size with 24 bits (red, green, blue – 8 bits)
  - video clips typically compressed in motion “avi” file structure

- **Measurements of distance** using the US image are common for anatomical sizing (e.g., fetal head diameter, circumference for estimate of fetal age). Large volumes of numbers are created in an output report for the study.

- **Ultrasound structured reports** include pertinent measurements (e.g., distance, fetal head diameter, blood velocity, blood flow, etc.) in the diagnostic report.

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**Definition 4.17: Ultrasound (US)**

US generates tomographic images of the *acoustic properties* of body tissues by sending short, high-frequency sound pulses into a specific volume, listening for echoes, and creating anatomic grayscale images. The evaluation of blood flow by Doppler signal analysis and/or color flow imaging are also important capabilities of US.

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**Key Concept 4.18: Ultrasound Acquisition Modes**

- **A-mode** is the amplitude modulated signals along a single line of the US beam.
- **T–M mode** is the time–motion analysis of repeated A-mode data with a stationary transducer.
- **B (brightness) scan mode** ultrasound records returning echo amplitudes of a moving US beam to create a two-dimensional grayscale acoustic image.
- **B-scan video clips** acquire a sequence of real-time US images in a specific anatomical region, usually stored as “avi” or “mpeg” and in color (24 bits).
- **Doppler ultrasound** uses frequency shifts of returning echoes in blood vessels for velocity and quantitative blood-flow analysis.
- **Color flow imaging** uses data generated by moving blood and frequency to “colorize” the motion and direction of blood cells in vessels.
- **3D and 4D** US uses tomographic and volumetric data to produce 3D surface renderings (note: 4D is 3D plus time).
• Video clips, measurement reports, and color display are not conducive to general PACS workstations, which promulgate the use of US “mini-PACS” implementations.

• Where is ultrasound used? Radiology (vascular, anatomical, obstetrics, breast, biopsy); cardiology (echocardiography); vascular laboratory (vascular surgery); obstetrics and gynecology (fetal imaging); emergency department; ophthalmology, among other users.

4.2.6 Nuclear Medicine (also known as Molecular Imaging)

• Single-Photon Emission Computed Tomography (SPECT) records planar images from multiple angles and uses images to reconstruct tomographic slices from the imaged volume.

• SPECT and X-ray CT (SPECT/CT) system are used in combination to provide a method for attenuation correction and correlation of metabolic activity with high-resolution anatomy for fused CT and SPECT image data.

• Positron Emission Tomography (PET) imaging uses positron emitters (elements that decay and release a positive electron) to produce annihilation photons. These elements are attached to a metabolic agent (e.g., glucose, as in fluorine-19 fluoro-deoxyglucose) and redistribute in the body. Two oppositely directed gamma-ray photons form a “line integral” of activity from which a tomographic slice can be determined.

• PET/CT systems are now standard, where the CT part of the system provides attenuation correction measurements for improving the quantitative accuracy of the PET uptake information as well as high-resolution anatomy display. Image fusion provides both physiological/metabolic information and associated high-resolution anatomical and structural information.

• Image sizes in nuclear medicine vary widely, depending on the technology and the exam type, but in general support of small matrices is typical (64 × 64, 128 × 128, 256 × 256). The use of CT in nuclear medicine is dramatically increasing the amount of data produced and archived.
4.2.7 Other Areas of Image Acquisition

It include dental (and dental 3D imaging), pathology (the largest image sizes and complex workflow), ophthalmology, dermatology, and a host of other image users. For dental imaging, the digital intra-oral X-ray image IOD addresses the needs for describing the unique acquisition characteristics and information necessary for dental practices. The visible light (VL) IOD is very relevant for much of the data being produced in pathology and dermatology.

Definitions 4.20: Modality Interfacing

**Source AE (application entity) title:** a unique name that identifies the specific modality to the PACS.

**Target AE title:** a name that identifies the PACS (e.g., image storage) to the modality. For a given IP address and port number, the AE title must be unique.

**IP address:** unique static address assigned to the modality client and the PACS server; IP addresses are used for transmission of image and patient demographic information from the client to the server over an electronic network with transmission control protocol/Internet protocol (TCP/IP).

**Port number:** specific port assignment to allow communication from a specific starting point on the client to a specific endpoint on the server; the IP address and the port number comprise a communication socket.

**Modality worklist (MWL) interface:** provides patient demographic and procedural information (type of study) from the scheduling module (e.g., Radiology Information System) to the modality console through a PACS “broker” that translates Health Level 7 (HL7) messages into compatible DICOM information.

4.3 Installation/Integration of Modalities with PACS and RIS

4.3.1 Network Subnets for Modalities

A reasonable scenario in a large institution is the partition of imaging modalities from the remainder of the Internet traffic to isolate and protect clinical imaging modalities from other general users of the Internet (e.g., printers, email, other clinical systems, etc.). This avoids traffic and collisions on the network, and also has the beneficial impact of protecting critical clinical systems from outside intrusion by more strictly controlling access.
4.3.2 Quality Control of Diagnostic Imaging Equipment – What Tests? How Often?

- The modality “system” includes not only the acquisition hardware and image processing capabilities but also the electronic interfaces and PACS operation that can determine how the images appear on the workstations for consumption by the radiologist.
- QC frequency is optimally implemented as a function of the likelihood of finding a problem; system components or human tasks that fail infrequently should be tested less often than those components that can change rapidly.
- Informatics professionals should have a working knowledge of the QC procedures and be able to recognize problems that are specific to the modality, the PACS and other electronic infrastructure, and understand the responsible parties for solutions to suboptimal performance.

**Step-by-Step 4.21: Installing a New Modality**


1. Check all vendor documentation, including DICOM conformance statements and interface specifications. Ensure that PACS can handle image-type support. Verify that information in image header will allow proper hanging protocols to be implemented.
2. Verify sample images (of all types, e.g., projection images, video clips, 3D rendering views, etc.) can be viewed and manipulated on the PACS.
3. Check the DICOM header information of the images and validate information with comparison to the DICOM standard.
4. Test the modality interface on the installed system using a test worklist provider system; ensure that information is properly presented and responses are generated as expected. Set the proper AE title, IP address, port number information of the PACS and also for the modality.
5. Connect the new modality to the production modality worklist provider; generate test images.
6. View images on test server/archive system as well as enterprise workstations to verify data integrity and consistency.
7. Generate test images for all types of image acquisition protocols, body parts, procedures. Check for worklist functionality, hanging protocols, overlay information (patient demographics, technique information, exposure data, etc.) on review workstations.
8. Implement network management monitoring, and send DICOM echo messages at regular intervals to detect issues before they impact system operations or workflow.
Remote vendor access to imaging modalities via virtual private network (VPN) access are a cost-effective way to evaluate systems with self-analyzing software and to provide remote support for many configuration issues.

Remote vendor access to imaging modalities via virtual private network (VPN) access are a cost-effective way to evaluate systems with self-analyzing software and to provide remote support for many configuration issues.

4.4 Conclusion

There are many informatics considerations and issues regarding diagnostic imaging modalities to be understood by imaging informatics specialists. Overarching is the need to consider the total imaging system – not just the modality – including the events that occur prior to, during, and after the image acquisition event. Only then can an objective evaluation be attained to verify the timely delivery of safe and effective patient care.

Definition 4.22: Quality Assurance and Quality Control

Quality assurance (QA) is the overarching program that asks the question, “Are we operating the devices correctly?” A subset of QA is quality control (QC) that asks the question, “Are the devices operating correctly?” Certainly, optimal QA requires optimal QC, but often overlooked is the human element, since imperfect operation of a technically optimal system will result in substandard image outcomes. Continuous quality improvement is a key factor for acting on QA and QC findings to strive for optimal patient care.

Further Reading 4.23

Pearls 4.24

- Diagnostic modalities generate the image data that form the basis of the PACS; assuring excellent image quality and robust demographic information is critically important in the management and care of patients.

- An imaging system concept must be kept in mind for all modalities, since the weakest link might not be directly related to the modality itself. Examples are poor image quality due to inadequate digital image display or calibration, image processing artifacts in images due to scaling errors, improper flat-field calibrations introducing detector image noise.

- The amount of data generated by cross-sectional imaging modalities and systems are increasing as new technologies produce and rely on volumetric datasets and 3D reconstruction methods. Scaling network bandwidth and storage needs and planning for growth and technological advances are crucial considerations.

- A universal workstation to review images from all modalities is currently not feasible with a single-vendor solution. Application-specific software and hardware capabilities, typically provided by application-programmer-interface (API) capabilities in conjunction with a “generic PACS” can allow third-party solutions to approach the specific needs of the clinical application required for efficient diagnostic image interpretation.

- Quality assurance and quality control procedures provide the framework to ensure correct operation of image acquisition systems and other electronic devices for the delivery of optimal patient care. Continued diligence and feedback to correct problems on an ongoing basis are a ticket for successful implementation of imaging modalities in an electronic network and PACS environment.

Suggested Reading


Self-Assessment Questions

1. The image matrix size of a computed tomography image is?
   a. $128 \times 128 \times 12$ bits
   b. $128 \times 192 \times 12$ bits
   c. $256 \times 256 \times 12$ bits
   d. $512 \times 512 \times 8$ bits
   e. $512 \times 512 \times 12$ bits

   As a follow-up, consider the other distracters in the question and think about the modalities that produce those size images.

2. Which one of the following modalities uses nonionizing radiation from interactions with the body to generate the resultant image?
   a. Pulsed fluoroscopy
   b. Computed tomography
   c. Positron emission tomography
   d. Magnetic resonance
   e. Single-photon emission computed tomography

3. Of the following, which modality has the largest data size for a single image?
   a. MRI with an 8 channel phased array coil
   b. CT with a 128 channel multidetector array
   c. DR chest X-ray with $43 \times 43$ cm FOV, $200 \, \mu m$ detector element
   d. Digital photospot camera with a 40 cm diameter intensifier
   e. Mammography with $24 \times 30$ cm FOV, $50 \, \mu m$ detector element

4. A radiographic image has areas of saturation and no anatomical information, but is acquired using an appropriate technique (kV and mAs). This outcome is likely due to which one of the following?
   a. histogram scaling error
   b. overexposure
   c. underexposure
   d. antiscatter grid
   e. exposure index miscalibration

5. Which procedure is used to transfer patient demographic information from the RIS to the image acquisition device?
   a. Performed procedure step (PPS)
   b. Presentation of grouped procedures (PGP)
   c. Key image note (KIN)
   d. Modality worklist (MWL)
   e. Portable data for imaging (PDI)
6. Which image acquisition technique uses annihilation radiation to create tomographic images?
   a. SPECT  
   b. PET  
   c. CT  
   d. Emission imaging  
   e. γ-ray absorptiometry
7. The largest drawback of radiography compared to computed tomography is ______.
   a. higher radiation dose  
   b. lower spatial resolution  
   c. anatomical superimposition  
   d. time required for the examination  
   e. image storage requirements
8. Which of the following is the most important environmental patient safety aspect concerning MRI?
   a. Tissue heating  
   b. RF noise  
   c. Ferromagnetic projectile  
   d. Gradient switching  
   e. Eddy currents
9. The window width and window level setting most appropriate for viewing a CT image when bones are being evaluated (e.g., wide contrast latitude) is closest to which setting? (WW is window width, WL is window level).
   a. WW = 400 WL = 40  
   b. WW = 2000 WL = 300  
   c. WW = 80 WL = 35  
   d. WW = 200 WL = 50  
   e. WW = 1500 WL = −700
10. The CT number most likely to be encountered in the lung area of a CT image is which of the following?
    a. −800  
    b. −20  
    c. 0  
    d. 500  
    e. 2000
11. Which of the following modalities has the highest spatial resolution?
    a. MRI  
    b. Fluoroscopy
c. CT
d. Radiography
e. Ultrasound

12. Which one of the following parameters for an MR image acquisition is user defined, rather than a property of the patient’s tissues?
   a. T1  
   b. T2  
   c. Proton density  
   d. TR  
   e. Blood flow

13. An attribute that a typical diagnostic PACS workstation used for ultrasound image review does not commonly provide is the ability to ______.
   a. display acoustic grayscale images  
   b. simultaneously play multiple avi video clips  
   c. retrieve archived ultrasound images  
   d. show color images for Doppler studies  
   e. use measurement tools for evaluating distances

14. Besides providing high-resolution anatomy fused with low-resolution metabolic activity, the other chief reason for CT and PET system combination is to ______.
   a. provide attenuation correction for the PET reconstruction  
   b. reduce the injected dose of the radionuclide  
   c. eliminate the need for a CT scan elsewhere  
   d. use the CT scan data for treatment planning  
   e. allow 3D rendering for improved diagnosis
Part II

Technology: The PACS Imaging Chain

Associate Editor: Daniel L. Rubin
Chapter 5
Workflow Steps in Radiology

R.L. “Skip” Kennedy

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5.1 Introduction

The understanding of workflow in Radiology is, properly, part of the larger domains of business process analysis (BPA) and business process modeling (BPM), for which extensive literature exists in the business administration literature outside of imaging informatics. However, some special and particular aspects of digital image management, such as the specific technical mechanisms of DICOM and HL7, as well as the interactions of these two standards and other emerging standards, need to be addressed to fully understand how data and processes interact in the context of a fully digital imaging environment. Fortunately, the integrating the healthcare enterprise (IHE) frameworks offer particularly useful models that specifically address and leverage both HL7 and DICOM capabilities in regard to workflow. Further, it is increasingly important for us to expand the scope of our understanding regarding imaging workflow to include the overall healthcare enterprise, to embrace the electronic medical record (EMR) and other enterprise systems, and to extend beyond the immediate radiology context into other medical imaging domains such as cardiology, dermatology, pathology, surgery, ophthalmology, and those other medical disciplines now increasingly engaged in digital imaging.
Much of the basis of film-based medical imaging workflow revolved around the fundamental nature and limitation of film itself – as a physical entity, the actual transport of film constituted much of what was, in the past, considered radiology “workflow.” Picture archiving and communications systems (PACS) have, at a very fundamental level, altered these assumptions and this understanding. The potentially ubiquitous nature of electronic imaging and reporting in healthcare has fundamentally changed the nature of imaging workflow from basic document management and the physical transport of film in radiology to the information flow of the larger healthcare enterprise. Since radiology information systems (RIS) most typically predate picture archival and communications systems (PACS) adoption, it is not at all surprising that many RIS still tend to address radiology workflow in both a fundamentally film-based, as well as a radiology-centric manner. To properly understand the current state of medical imaging workflow, we must move well beyond this model.

5.2 Documentation and Process Flow

Although we must still apply the specifics of HL7 and DICOM to traditional business process analysis and modeling to be fully useful for our purposes, the tools available from the general disciplines of business administration remain extremely valuable. Process flow diagramming, in particular, offers us great value for documentation of information flow and the various event triggers that drive imaging workflow. Several standard texts exist for understanding process documentation and are not covered here. However, it remains an essential exercise for any PACS and RIS deployment to document intended workflow using the standard business process documentation tools available. Figure 5.1 is an example of a typical such diagram, incorporating RIS, PACS, report management, and EMR workflow steps. The key to this process is to design workflow to achieve desired clinical results, to the degree possible with the new systems, rather than to simply re-implement electronically those same workflows that defined film-based radiology imaging. We will need to build what is needed in the present (and future) rather than rebuild those workflows and processes we have utilized in the past.

**Definition 5.1: IHE**

Integrating the Healthcare Enterprise is an initiative that has created a framework for medical workflow by which different electronic information systems can exchange information.
5.3 Key Steps of Radiology Workflow

One of the essential points of understanding the HL7 and DICOM aspects of digital image workflow is the concept of event triggers.

**Further Reading 5.2: Business Process Analysis**

For example, the action of a technologist clicking on a button on the CT scanner, and initiating a DICOM transmission to the PACS of the completed study may trigger yet other automated actions further in the workflow, such as potentially the PACS forwarding a HL7 message to the EMR signaling new image availability.

Understanding these workflow triggers, in most cases, involves understanding the state conditions of the underlying protocols – typically DICOM and HL7, but increasingly also web services such as SOAP – as well as the actual events that these represent in the actual business logic.

The translation of the business logic to the appropriate protocol messaging state is the key to the implementation of functional workflow in digital imaging.

### 5.3.1 Radiologist Workflow Steps

- Log in to PACS
- Set worklist filters/choose cases
- Launch case
- Collect clinical data/prior exams
- Review and interpret images
- Dictate report
- Personally convey urgent or unexpected findings
- Review and sign report (may be performed individually or as a batch)
- Protocol and check ongoing cases

### 5.3.2 Technologist Workflow Steps

- Determine next patient/claim patient in RIS
- Retrieve patient
- Determine protocol
- Obtain images
- Check images for quality
- Postprocess to create additional images
5.3.3 Referring Clinician Workflow Steps

- Order study
  - Computerized physician order entry
  - Paper order in patient’s chart
  - Verbal order to nurse or clerk
- Provide clinical information for radiologist
- Review radiologist report
  - Online
  - In the EMR
  - Paper report in the patient’s chart
  - Contact radiologist for clarification/discussion

5.3.4 Other Personnel with Critical Workflow

- Transcriptionist – workflow strongly determined by speech recognition and dictation software
- Nurses
  - Radiology nurses
  - Ward nurses

Our Experience 5.5: Paperless Workflow

One of the major areas of workflow inefficiency in most radiology departments is the paper tokens that are passed from one person to another to follow the flow of the patients and their images through the departments. Changing from a paper-based to a paperless workflow is very inviting, but it is easy to get caught by minor issues that will prevent full implementation. Usually, the workflow of the radiologist is carefully considered, and if dictation is integrated with PACS, then the PACS will have the software elements necessary to abandon paper. But do not forget that other personnel rely on those same paper tokens! Taking them out of the hands of the radiologists may not be adequate unless communication software between nurses, techs, and physicians is robust. For example, technologists may use the paper requisitions to write notes to the radiologist, explaining why an exam is of suboptimal quality or providing new clinical information. There needs to be an alternate means of communicating that information when you go paperless.
• PACS support personnel – need dashboards to stay ahead of hardware failures
• File room clerks – even after the transition to PACS, still needed to find comparison films and create CDs
• Ward clerks – often responsible for actually ordering the study, upon a physician’s order
• Transportation personnel – take inpatients from their rooms to radiology and back

5.4 IHE Workflow Models

In the IHE model, imaging workflow is comprised of a hierarchical sequence of several components: order, requested procedure, procedure step, worklist, and reports. Defining and combining these steps and components allow us to design digital imaging workflow. The formalization and rigor of the IHE workflow model provide us with a more exact semantic context for the steps of digital image workflow and allow us to merge different workflow models with shared context.

• An order represents a formal request, typically from a referring provider, for a specific or general service, representing certain actions or work products. Since reimbursement is closely linked to order status and processing, orders most typically originate from external systems, such as HIS or EMRs supporting electronic order entry. These are typically transmitted to a RIS and to PACS to support integration and automated modality worklist processing.

• A requested procedure represents a fundamental work unit, typically performed together within an encounter that is comprised of one or more procedure steps typically performed together during this patient encounter. Multiple procedure steps may be required to satisfy the procedure and the corresponding order. An example of this might be for a “CT Head Scan” within the EMR order entry system.

• A procedure step represents the discrete and indivisible steps that comprise the requested procedure as an entity. Since these are interrelated, they need to be performed within the encounter itself, or in a designated sequence. These are represented within a worklist and are typically associated with specific common procedural terminology (CPT) coding. In other cases, procedure steps may also represent required steps that may or may or may not be performed within an encounter, such as treadmill or radionuclide injection.

• A worklist represents procedures and procedure steps that are to be performed. Typically, now, this is made available and transmitted to the performing modality via the DICOM modality worklist service, to avoid
repeated manual data entry and resulting data entry error. Design of work-
list management is one of the most essential PACS design criteria, as it
heavily contributes to both efficiency as well as data integrity of the imaging
products of reports and the images themselves.

- **Reports** are most typically the result of radiologist interpretation,
  although there is now an increasing focus on structured reporting
  resulting from technologist workflow processes as well as automated
  content (such as protocol details and tabular data) directly from the
  modalities themselves.

The Integrating the HealthCare Enterprise (IHE) initiative has pro-
vided us with invaluable templates for key aspects of medical imaging
workflow, in the form of several key integration profiles for radiology. While the scope of IHE is now much
larger than imaging itself, and many additional integration profiles for radiology exist, the reader is urged to
refer to the following list as a founda-
tion for approaching the various IHE models for workflow in digital imaging:

- Scheduled workflow (SWF) integrates ordering, scheduling, imaging acquisition, storage, and viewing for
  radiology exams.
- Patient information reconciliation (PIR) coordinates reconciliation of the
  patient record when images are acquired for unidentified (e.g., trauma), or
  misidentified patients.
- Postprocessing workflow (PWF) provides worklists, status, and result track-
ing for postacquisition tasks, such as computer-aided detection or image
  processing.
- Reporting workflow (RWF) provides worklists, status, and result tracking for reporting tasks, such as dictation, transcription and
  verification.
- Import reconciliation workflow (IRWF) manages importing images
  from CDs, hardcopy, etc., and reconciling identifiers to match local
  values.
- Portable data for imaging (PDI) provides reliable interchange of image data
  and diagnostic reports on CDs for importing, printing, or optionally, dis-
  playing in a browser.
- Evidence documents (ED) specifies how data objects such as digital mea-
  surements are created, exchanged, and used.

---

**Further Reading 5.6: IHE**

- IHE website. Available at: http://www.ihe.net
- Simple image and numeric report (SINR) specifies how diagnostic radiology reports (including images and numeric data) are created, exchanged, and used.
- Key image note (KIN) lets users flag images as significant (e.g., for referring, for surgery, etc.) and add notes.
- Consistent presentation of images (CPI) maintains consistent intensity and image transformations between different hardcopy and softcopy devices.
- Presentation of grouped procedures (PGP) facilitates viewing and reporting on images for individual requested procedures (e.g., head, chest, abdomen) that an operator has grouped into a single scan.
- Access to radiology information (ARI) shares images, diagnostic reports, and related information inside a single network.

As these integration profiles expand and refine further, they serve as templates for vendor interoperability, fully supported by the technical specifics of DICOM and HL7 in the IHE framework documents. Figure 5.2 details the first, and probably most fundamental, of the IHE Integration Profiles – the \textbf{Scheduled workflow profile}. Dozens of other profiles now exist, and more are in development. Essentially all aspects of digital imaging workflow are now represented within the various IHE integration profiles currently available.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{scheduled_workflow.png}
\caption{IHE Scheduled Workflow. Reprinted from the IHE Radiology Technical Framework White Paper 2004–2005 with permission from IHE International.}
\end{figure}
5.5 Goals of Workflow Analysis

- The goal for any workflow analysis and workflow engineering process is, ultimately, to improve and enhance the workflows for **efficiency, reliability, fault tolerance, and transparency** to the clinical users.
- Workflow that represents many discrete steps that the clinical users must remember individually is to be avoided.
- Where possible, the concept of user interface “navigators” is particularly valuable when applied to sequential repetitive workflow.
- Where feasible, any given step that requires a **predecessor step** to be meaningful should not be available until the requisite predecessor has been completed. (Such as a radiologist reporting on a study for which a technologist has not yet completed or performed QA).
- **Exception workflows** for which these steps must, necessarily, be performed out of normal sequence should be available, but still allow process state recovery. (As an example, the IHE profile for patient information reconciliation (PIR) for reconciliation of unidentified or misidentified patient/study information.)
- A further goal for digital imaging workflow design is to facilitate **interoperability**. This is key deliverable of the IHE initiative.
  - Vendor-specific workflow is seldom capable of addressing enterprise requirements – while a “single-vendor solution” may be feasible with the confines of radiology, few, if any, vendors would be capable of addressing the needs of multiple departments and the enterprise EMR.
  - One of the fundamental goals of IHE is to facilitate vendor interoperability by the abstraction of the various system roles and the definition of standard protocol framework to the construction of workflows.

5.6 Summary

The design and testing of digital imaging workflow will be addressed more fully in Chapter 17, but the basics of approaching an understanding of these workflows lie in three areas:

- leveraging existing business tools outside of Informatics for workflow documentation and analysis methodologies.
- understanding the technical specifics of DICOM and HL7 as they apply to and drive digital imaging workflow.
- understanding and leveraging the IHE workflow models as templates for local workflow.

A great deal of particularly valuable work has been done in developing the IHE integration profiles and frameworks, and the study of these will prove valuable to any effort regarding workflow engineering. While it is likely that not
every aspect of the IHE integration profiles may apply precisely to all specific local clinical requirements, it is equally unlikely that any institution developing and deploying PACS at this time would not find the majority of the IHE workflow models directly applicable and valuable. The use of the IHE technical frameworks for achieving vendor interoperability as well as regional institutional interoperability in the future are key developments and resources in these efforts.

Digital imaging has now moved well beyond the confines of radiology, both in terms of multiple imaging departments as well as servicing the entire enterprise as its customer base. Early implementations of PACS and RIS were, by necessity, limited in scope, but modern digital imaging workflow has as its expanded scope, multiple departments and enterprise access. The culmination of these changes will almost certainly be enterprise, regional, and finally national EMRs that encompass digital imaging. We must build workflows today to support and embrace these futures.

**Self-Assessment Questions**

1. Which of these is NOT a usual element of radiologist workflow?
   a. obtain images
   b. convey unexpected findings
   c. protocol ongoing cases
   d. collect clinical data

2. Which of these is NOT a usual element of technologist workflow?
   a. send images to PACS
   b. check images for quality
   c. postprocess the study to create new images
   d. bring the patient to the radiology department

**Further Reading 5.7:**

**RIS and PACS**


**Pearls 5.8**

- Workflows for different personnel are inextricably linked.
- IHE provides a useful framework for radiology workflow.
- Workflow improvements should address the efficiency, reliability fault tolerance, and transparency of workflow.
- Improved communication between different software programs allows for more efficient workflow.
3. Which of these is NOT a usual element of clinician workflow?
   a. order study
   b. dictate radiology reports
   c. review radiologist report
   d. provide clinical data

4. Which of these is NOT an IHE integration profile?
   a. reporting workflow
   b. evidence documents
   c. consistent presentation of images
   d. procedure step

5. Which of these is NOT a hierarchical IHE component?
   a. postprocessing
   b. order
   c. requested procedure
   d. worklist

6. Imagine transitioning to paperless workflow in your department. Think of idiosyncratic or unpredictable ways that paper is used that would need to be replaced.

7. Think of questions you would ask a vendor to make sure that their product has the IHE profiles you need.
Chapter 6
Standards and Interoperability

David S. Channin

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6.1 Introduction

In a complex information technology (IT) environment such as medical imaging, no single information system can provide all of the functionality necessary for safe, high-quality, accurate, and efficient operations. Information systems must, therefore, share data and status with each other.

This information can be shared either through proprietary interfaces or through IT standards. Proprietary interfaces are typically expensive to develop and difficult to maintain. Proprietary interfaces evolve slowly because market demand for any given configuration may be very small. Given their nature, these interfaces are often confidential. This makes understanding their rationale and workings difficult. Use of proprietary interfaces is usually tightly controlled by the vendor(s) and this impedes innovation and research.

IT standards, on the other hand, are consensus documents that define information system behavior in an open fashion. In the United States, the American National Standards Institute (ANSI) coordinates standards development. ANSI accredits Standards Development Organizations (SDOs), the latter most often consortia of industry, academia, and government. ANSI also designates United States Technical Advisory Groups (TAGs) to the International Organization for Standardization (ISO).
Organizations accredited by ANSI must accept the internationally accepted principles of standardization: transparency, openness, impartiality, effectiveness and relevance, consensus, performance-based, coherence, due process, and technical assistance. NIST, the National Institute of Standards and Technology, a branch of the US Department of Commerce, is responsible for coordinating the use of standards by US Government agencies. NIST is also an accredited standards development organization.

Two of the most important ANSI-designated SDOs in healthcare are Health Level Seven (HL7) and the National Electrical Manufacturer’s Association (NEMA). HL7 is responsible for the development of its eponymous standard, HL7, while NEMA is the secretariat for the Digital Imaging and Communications in Medicine or DICOM standard. Both of these standards are discussed in detail below. These standards, however, like many others stand on the shoulders of modern computer networks and the Internet.

Computer networking and the Internet are only possible because of hardware, protocol, and software standards. Electronic hardware standards are typically developed by IEEE (formerly the Institute of Electrical and Electronics Engineers, Inc.; now known by its initials). According to Merriam Webster’s Dictionary, a protocol is both, “a code prescribing strict adherence to correct etiquette and precedence (as in diplomatic exchange and in the military services),” and “a set of conventions governing the treatment and especially the formatting of data in an electronic communications system.”

Networking protocols are developed by the Internet Engineering Task Force (IETF) under the architectural guidance of the Internet Architecture Board (IAB). Both are components of the Internet Society. The IETF publishes standards and proposed standards as Request For Comments (RFCs) reflecting the collaborative, consensus nature of standards development. Much of the early history of the Internet can be gleaned from early RFCs, the earliest of which date from 1969. Software standards for the Internet and the World Wide Web, including the hypertext markup language (HTML), the extensible markup language (XML), and the web ontology language (OWL), are developed and maintained by the World Wide Web Consortium known as W3C. W3C publishes these standards as “Recommendations.”

ASTM International, formerly known as the American Society for Testing and Materials, is another

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Further Reading 6.1
- Overview of the US Standardization System. Available at: http://publicaaansi.org

Further Reading 6.2: Network Protocols

Further Reading 6.3: The World Wide Web Consortium
- Available at: http://wwww3org/Consortium/Overview
SDO focused on technical standards for materials, products, systems, and services, some of which are related to healthcare. Recently, for example, ASTM collaborated in the development of the Continuity of Care Record, an electronic patient transfer information sheet.

Organization for the Advancement of Structured Information Standards (OASIS) is a standards development consortium that develops (predominantly) XML and XML-related standards for e-commerce. Several OASIS standards have been adopted for use in healthcare.

Lastly, while standards are necessary to the interoperability required for operations in complex healthcare information systems environments, they are not sufficient. Many problems can be solved in different ways using different standards. Many standards contain significant variability and optionality that impair their usefulness. To remedy this situation, at least in healthcare, the Radiological Society of North America (RSNA), later in conjunction with the Healthcare Information and Management Systems Society (HIMSS), formed the Integrating the Healthcare Enterprise (IHE) initiative. IHE is now an international organization with a formalized process to develop technical frameworks that specify precisely how standards shall be used to solve specific problems. Several IHE technical frameworks are discussed below.

While it is impossible for any one individual to master all of the standards, protocols, hardware, and technical frameworks that affect our lives in healthcare, the imaging informatics professional (IIP) must be fluent in the common standards and technical frameworks that dominate medical imaging. He or she must be capable of searching for and identifying new standards. The IIP must be able to incorporate specifications for standards and interoperability into requests for proposals and purchase documents and know how to validate their installation. The successful IIP will remain current as these standards and frameworks evolve rapidly so as to shield as much as possible his or her institution from obsolescence. As Alan Kay once said, “The best way to predict the future is to invent it” and leaders in the imaging informatics profession participate in the development of new standards.

6.2 Information Technology Standards Relevant to Imaging

6.2.1 Internet Standards

- IETF RFC1305 Network Time Protocol (NTP). NTP is used to synchronize clocks in computer systems. When systems communicate with each other, it
is critical that their clocks be synchronized so that messages are interpreted in the appropriate time frame.

- **IETF RFC1738, Uniform Resource Locators.** This RFC “specifies a Uniform Resource Locator (URL), the syntax and semantics of formalized information for location and access of resources via the Internet.”
- **IETF RFC1866 Hypertext Markup Language (HTML).** This RFC formalized the initial description of HTML that has been in use since 1990.
- **IETF RFC2045 MIME (Multipurpose Internet Message Extensions).** Prior to MIME, e-mail messages could only include ASCII text. With the advent of MIME, e-mail messages could be extended to include many different non-textual content elements including DICOM images.
- **IETF RFC2246 Transport Layer Security (TLS).** TLS and its predecessor Secure Sockets Layer (SSL) define cryptographic mechanisms for securing the content of Internet transactions.
- **IETF RFC2616 HyperText Transfer Protocol (HTTP).** This RFC defines the basic protocol for transferring HTML content between the client and the server. This is the backbone of the World Wide Web.
- **IETF RFC2821 Simple Mail Transfer Protocol (SMTP).** SMTP and now Internet Message Access Protocol (IMAP; RFC 3501) as well as Post Office Protocol (POP; RFC2449) are the basis for e-mail transactions on the Internet.
- **IETF RFC3164 The BSD Syslog Protocol.** BSD Syslog and its reliable extension (Reliable Delivery for Syslog; RFC 3195) specify a very simple, yet powerful mechanism for delivering a log file payload to a server for audit trail and logging purposes.
- **W3C Recommendation Extensible Markup Language (XML).** XML is a free, open standard for encoding structured data and serializing it for communication between systems. XML is being used as the method of choice for almost all new standards development related to distributed systems. It is rapidly penetrating healthcare information technology standards, for example in HL7 version 3, described below.

### 6.2.2 Digital Imaging and Communications in Medicine (DICOM)

- DICOM is managed by the Medical and Imaging Technical Alliance (MITA), a division of NEMA.
- DICOM is an ANSI, ISO, and European standard for medical imaging.
- The DICOM Standards Committee is organized as a set of **working groups** (Table 6.1).
- The current version of the base standard is DICOM PS 3 2008.
- The DICOM standard is a structured multipart document. DICOM PS 3 2008 consists of 18 parts.

Further Reading 6.5: DICOM Working Groups
- Available at: [http://medical.ne ma.org/dicom/geninfo/Strategy.pdf](http://medical.nema.org/dicom/geninfo/Strategy.pdf)
Vendors of medical imaging equipment can claim conformance to the DICOM standard. In doing so, they must produce a DICOM conformance statement in accordance with Part 2 of the standard. Comparison of two vendors’ conformance statements will indicate if the two devices can operate. Without an IHE integration statement, there is enough variability in DICOM deployment configuration that two devices with matching conformance statements may not interoperate as desired (Table 6.2).

**Table 6.1** The DICOM Working Groups

<table>
<thead>
<tr>
<th>Working Group</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – Cardiac and Vascular Information</td>
<td>14 – Security</td>
</tr>
<tr>
<td>2 – Projection Radiography and Angiography</td>
<td>15 – Mammography and CAD</td>
</tr>
<tr>
<td>3 – Nuclear Medicine</td>
<td>16 – Magnetic Resonance</td>
</tr>
<tr>
<td>4 – Compression</td>
<td>17 – 3D</td>
</tr>
<tr>
<td>5 – Exchange Media</td>
<td>18 – Clinical Trials and Education</td>
</tr>
<tr>
<td>6 – BASE STANDARD</td>
<td>19 – Dermatology</td>
</tr>
<tr>
<td>7 – Radiotherapy</td>
<td>20 – Integration of Imaging and Information Systems</td>
</tr>
<tr>
<td>8 – Structured Reporting</td>
<td>21 – Computed Tomography</td>
</tr>
<tr>
<td>9 – Ophthalmology</td>
<td>22 – Dentistry</td>
</tr>
<tr>
<td>10 – Strategic Advisory</td>
<td>23 – Application Hosting</td>
</tr>
<tr>
<td>11 – Display Function Standard</td>
<td>24 – DICOM in Surgery</td>
</tr>
<tr>
<td>12 – Ultrasound</td>
<td>25 – Veterinary</td>
</tr>
<tr>
<td>13 – Visible Light</td>
<td>26 – Pathology</td>
</tr>
</tbody>
</table>

**Further Reading 6.6: DICOM**

- Part 1 of DICOM, “Introduction and Overview,” and Part 17, “Explanatory Information,” should be mandatory reading for anyone working with DICOM.

**Key Concept 6.7: Buying DICOM**

Purchasers of medical imaging equipment should mandate conformance to the DICOM standard as a contractual obligation of each purchase.
Systems that implement DICOM functionality are called **DICOM Application Entities** (AE). Application Entities have titles that name them, an IP address that defines their network location, and a port number that defines the network port on which the entity is listening for DICOM communications.

- It is important to recognize that DICOM is based on a model of the real world. In that model, patients have imaging studies, studies contain series of images and each series of images contains specific images. The DICOM model of the real world is fairly complex, representing as it does a complex real world.

- In general, DICOM defines, formats, transmits, and manipulates **information objects**. Information object definitions (IODs) are found in the annexes of Part 3 of the standard. There are 53 IODs in the current standard. Note that not all DICOM objects are image objects. There are report objects and objects used to convey status.

- Each IOD is made up of modules that contain information about a particular information entity (IE). The module tables for all IODs are found in Annex A of Part 3. The **DIOCM CR IOD module table** is shown in Fig. 6.1. The optionality of modules is specified in the Usage column of the IOD module table. “M” is mandatory, “U” is user optional, and “C” is conditional.

- The specific contents of each module are specified in Annex C of Part 3. Each module is composed of a certain number of DICOM data elements. A portion of the Patient Module Attributes table that defines the data elements in the patient module is shown in Fig. 6.2.

---

**Definition 6.8: Information Object Definition**

An information object definition is a data model of a real-world object. For example, the DICOM computed tomography (CT) information object definition is a model of all the information contained in a CT study.

**Definition 6.9: Information Entity**

An information entity represents a real-world entity. The “Patient IE” is an information entity that represents the real-world patient.

**Definition 6.10: DICOM Data Element**

A DICOM data element is the smallest unit of information in a DICOM information object. Each data element has a tag that consists of a group number and an element number usually shown in hexadecimal and in parentheses (e.g., XXXX, YYYY). Each data element has a value representation (VR) that defines what kind of data it is. Each data element also has a value multiplicity (VM) that specifies whether the element can contain multiple values and if so, how many.
### CR IMAGE IOD MODULES

<table>
<thead>
<tr>
<th>IE</th>
<th>Module</th>
<th>Reference</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient</td>
<td>Patient</td>
<td>C.7.1.1</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Clinical Trial Subject</td>
<td>C.7.1.3</td>
<td>U</td>
</tr>
<tr>
<td>Study</td>
<td>General Study</td>
<td>C.7.2.1</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Patient Study</td>
<td>C.7.2.2</td>
<td>U</td>
</tr>
<tr>
<td></td>
<td>Clinical Trial Study</td>
<td>C.7.2.3</td>
<td>U</td>
</tr>
<tr>
<td>Series</td>
<td>General Series</td>
<td>C.7.3.1</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>CR Series</td>
<td>C.8.1.1</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Clinical Trial Series</td>
<td>C.7.3.2</td>
<td>U</td>
</tr>
<tr>
<td>Equipment</td>
<td>General Equipment</td>
<td>C.7.5.1</td>
<td>M</td>
</tr>
<tr>
<td>Image</td>
<td>General Image</td>
<td>C.7.6.1</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Image Pixel</td>
<td>C.7.6.3</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Contrast/ bolus</td>
<td>C.7.6.4</td>
<td>C - Required if contrast media was used in this image</td>
</tr>
<tr>
<td></td>
<td>Display Shutter</td>
<td>C.7.6.11</td>
<td>U</td>
</tr>
<tr>
<td></td>
<td>Device</td>
<td>C.7.6.12</td>
<td>U</td>
</tr>
<tr>
<td></td>
<td>CR Image</td>
<td>C.8.1.2</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Overlay Plane</td>
<td>C.9.2</td>
<td>U</td>
</tr>
<tr>
<td></td>
<td>Modality LUT</td>
<td>C.11.1</td>
<td>U</td>
</tr>
<tr>
<td></td>
<td>VOILUT</td>
<td>C.11.2</td>
<td>U</td>
</tr>
<tr>
<td></td>
<td>SOP Common</td>
<td>C.12.1</td>
<td>M</td>
</tr>
</tbody>
</table>

Fig. 6.1 The DICOM CR IOD Modules.

### PATIENT MODULE ATTRIBUTES

<table>
<thead>
<tr>
<th>Attribute Name</th>
<th>Tag</th>
<th>Type</th>
<th>Attribute Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient's Name</td>
<td>(0010,0010)</td>
<td>2</td>
<td>Patient's full name.</td>
</tr>
<tr>
<td>Patient ID</td>
<td>(0010,0020)</td>
<td>2</td>
<td>Primary hospital identification number or code for the patient.</td>
</tr>
<tr>
<td>Issuer of Patient ID</td>
<td>(0010,0021)</td>
<td>3</td>
<td>Identifier of the Assigning Authority that issued the Patient ID.</td>
</tr>
<tr>
<td>Patient's Birth Date</td>
<td>(0010,0030)</td>
<td>2</td>
<td>Birth date of the patient.</td>
</tr>
<tr>
<td>Patient's Sex</td>
<td>(0010,0040)</td>
<td>2</td>
<td>Sex of the named patient. Enumerated Values: M = male, F = female, O = other.</td>
</tr>
<tr>
<td>Referenced Patient Sequence</td>
<td>(0008,1120)</td>
<td>3</td>
<td>A sequence that provides reference to a Patient SOP Class/Instance pair. Only a single item shall be permitted in this Sequence.</td>
</tr>
</tbody>
</table>

> `Include SOP Instance Reference Macro Table 10-11`

<table>
<thead>
<tr>
<th>Attribute Name</th>
<th>Tag</th>
<th>Type</th>
<th>Attribute Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient's Birth Time</td>
<td>(0010,0032)</td>
<td>3</td>
<td>Birth time of the patient.</td>
</tr>
<tr>
<td>Other Patient IDs</td>
<td>(0010,1000)</td>
<td>3</td>
<td>Other identification numbers or codes used to identify the patient.</td>
</tr>
</tbody>
</table>

Fig. 6.2 The DICOM Patient Module Attributes table (portion).
The “type” of a data element refers to its optionality within the module. Type 1 elements are mandatory and must be present in the DICOM object. Type 2 elements are also mandatory and must be present, but if the entity does not know the value, the value may be blank. There are type 2C elements that are mandatory in certain circumstances. Type 3 data elements, no matter how important, are optional and are not required to be present.

- Some data elements have sequences of elements that are specified by a macro. The content of some data elements and some macros is constrained to certain terms. All constrained vocabulary referenced in the DICOM standard is found in DICOM Part 16, the DICOM Content Mapping Resource.

- The DICOM data elements are stored in the DICOM IODs in order by group number and then by element number. If you examine a DICOM “header,” you will note that the elements show up in this order and are not grouped according to the module in which they were defined.

- Every instance of a DICOM object gets a unique identifier (UID) when it is created. UIDs are long strings of digits separated by “.”. The most commonly recognized UID are the Study UID, the Series UID, and the SOP Instance UID. The latter refers to an individual image.

- DICOM is a transactional standard and defines services to manipulate DICOM objects. Examples of DICOM services are storage, query/retrieve, patient management, print management, storage commitment, etc. DICOM defines 22 Service classes in Part 4.

- Before DICOM applications exchange information, they negotiate an association that defines certain parameters of how they are going to communicate. This association negotiation is

---

**Key Concept 6.11: Private Elements**

All DICOM data elements have even group numbers. Vendors can use odd group numbers to store information they consider private and proprietary. You will see these in DICOM headers, but the meaning is often obscure.

**Key Concept 6.12: Unique Identifier (UID)**

A UID is a string of characters that can be used to uniquely identify an object in the known universe. DICOM uses UIDs that are based on ANSI root numbers assigned to each vendor. Vendors typically attach proprietary model information and date and time stamps to make the UIDs unique.

**Definition 6.13: DICOM Service**

A DICOM service is a specific set of operations to be performed. For example, the DICOM storage service class defines the operations necessary to facilitate the transfer of DICOM objects from one system to another.
critical to successful DICOM communications. If two devices do not share common association types (as identified in their conformance statement), they will not be able to negotiate an association.

- Services are combined with Information objects into service object pairs or SOP classes. Each combination of object and service is called out independently in DICOM. For example, a system that does storage of CT objects may not store structured reporting objects. The specific SOP classes are enumerated in the DICOM data dictionary, Part 6.
- For any given SOP class, the service class user (SCU) invokes the operations and the service class provider (SCP) performs the operations.
- The DICOM standard can seem intimidating. With this introduction and at least one case of beer, however, most people will be able to sit down with the standard and read the necessary portions when needed.

### 6.2.3 Health Level Seven (HL7)

- Health Level Seven (HL7), an independent, not-for-profit, organization is an ANSI accredited healthcare SDO headquartered in Ann Arbor, Michigan.
- HL7 has developed a number of standards over the years. The most well known and most widely implemented is the HL7 Messaging Standard Version 2: An Application Protocol for Electronic Data Exchange in Healthcare Environments, commonly known as HL7v2. Version 2.5 is the most current but many implementations of early versions of v2 remain in use.

#### Our Experience 6.14: What’s Wrong with HL7v2?

“Offering lots of optionality and thus flexibility, the V2.x series of messages were widely implemented and very successful. These messages evolved over several years using a ‘bottom-up’ approach that has addressed individual needs through an evolving ad-hoc methodology. There is neither a consistent view of that data that HL7 moves nor that data’s relationship to other data. HL7’s success is also largely attributable to its flexibility. It contains many optional data elements and data segments, making it adaptable to almost any site. While providing great flexibility, its optionality also makes it impossible to have reliable conformance tests of any vendor’s implementation and also forces implementers to spend more time analyzing and planning their interfaces to ensure that both parties are using the same optional features.”

– HL7 Version 3 website

- HL7v2 defines events that trigger flow of information between systems. For example, “a patient is admitted” is a typical trigger event. There are 123 message types that serve over 280 defined event types. Each message is identified by a three-letter code that appears in the header of the message.
ADT messages are related to patients, in particular, admission, discharge, and transfer of patients within a facility. This is how the patient registration process is communicated.

ORM messages are used to place orders and convey order status between systems. An order for a radiology procedure would typically be conveyed between an order placer system (e.g., an electronic medical record) and an order filler (e.g., a radiology information system [RIS]) by an ORM message.

ORU messages are typically used to convey the results of orders, for example, a radiology report.

HL7 v2 messages are ASCII text. Each message is composed of (a standardized) set of segments.


Segments are logical groupings of data fields and are specified, in order, for each message type. Segments may be required or optional and occur once or be repeated.

A sample ADT message, extracted from the standard, shown in Fig. 6.3.

In institutions of any significant size, HL7 messages are typically sent from the originating system to an HL7 message passing engine. This obviates the need to have each system send each message to each recipient.

**EXAMPLE TRANSACTIONS**

Admit/visit notification - event A01 (admitted patient)

```
MSH|A1|ADT1|GOOD HEALTH HOSPITAL|GHH LAB, INC.|GOOD HEALTH HOSPITAL|19980081126|SECURITY|ADT_A01|ADT_A01|MSG00001|P|2.5.1|<cr>
EVN|A01|2007081811233|<cr>
PID|1||PATID12345|5|W1|ADT1|MR|GOOD HEALTH HOSPITAL|1234567890|||EVERYMAN|ADAM|A||11|19610615|M||12222 HOME STREET|GREENSBORO|NC|24704-1020|GL|555|555-004||555|555-550-004||11|11|
PRTID123450012|2|M10|ADT1|AN|A|444333333|98765|NC|<cr>
NKL|1||NUCLEAR|W|MED|SPO|SPOUSE||||HK||NEXT OF KIN<cr>
PVL|1|1|2000|2012|01|||1004777|ATTEND|AARON|A||SUR|||ADMIA0|<cr>
```

Patient Adam A. Everyman, III was admitted on July 18, 2007 at 11:23 a.m. by doctor Aaron A. Attending (#004777) for surgery (SUR). He has been assigned to room 2012, bed 01 on nursing unit 2000.

The message was sent from system ADT1 at the Good Health Hospital site to system GHH Lab, also at the Good Health Hospital site, on the same date as the admission took place, but three minutes after the admit.

**Fig. 6.3** A Sample ADT message.
The HL7 message passing engine can also be used to filter, map, and data mine the messages as they pass. This can be very helpful in debugging complex installations.

6.2.3.1 HL7 Version 3

- Recognizing the limitations of HL7 version 2, the HL7 organization began developing a replacement entitled, “HL7 version 3.”
- Has a well-defined methodology for the development of standardized transactions.
- Transactions are encoded and serialized in XML.
- Has a well-defined information model, entitled, the “HL7 Reference Information Model (RIM).” The RIM defines a model of healthcare that is the basis for the standardized transactions.
- Relies heavily on standardized and controlled terminologies.
- Also includes the Clinical Document Architecture (CDA), a standard method for creating human readable and machine computable, authenticated documents in XML, based on the reference information model.
- Along with CDA, will be at the core of healthcare information standards.

6.3 Interoperability

6.3.1 Integrating the Healthcare Enterprise (IHE)

- IHE International is a member organization that promotes the use of information technology standards to solve specific complex problems of healthcare information system interoperability.
- Founded by the Radiological Society of North America in 1999, and soon joined by the Healthcare Information Management and Systems Society (HIMSS), IHE now consists of over 150 member organizations that include professional societies, SDOs, academic centers, government agencies, and industry.
- IHE is organized into domains along the lines similar to a clinical enterprise: Cardiology, Eye Care, IT infrastructure, Laboratory, Patient Care Coordination, Quality, Patient Care Devices, and Radiology (includes Mammography and Nuclear Medicine).
- Each domain organizes into planning and technical committees. The planning committees strategize the direction for the domain and coordinate

Pearl 6.18: IHE

IHE operates a wiki where the new development work is done. It can be found at wiki.IHE.net
activity within and across domains. The technical committees develop the technical framework details.

- The IHE domains all operate in a similar fashion. Healthcare providers, institutions, or vendors identify a problem. Brief proposals to address the problem are developed. The planning committee reviews and votes on which problems to tackle in a given year. The technical committees then develop an integration profile that describes the specific problem, the standards used to solve the problem, and the specifics of the proposed solution. The integration profile is reviewed within IHE and then released for public comment. After the public comment period the integration profile is released for trial implementation and scheduled to be included in the connect-a-thon. After appearing in the connect-a-thon, the profile is released and incorporated into the technical framework for that domain.

- IHE abstracts the notion of healthcare information system to a set of IHE actors. On occasion, IHE will mandate grouping of IHE actors, but, in general, IHE actors stand alone.

- In general, volume one of a technical framework defines the integration profiles. Volume two defines the standards and transactions used. Volume three defines internationalization that may have to occur as well as appendix information.

- Vendors claiming conformance to IHE technical frameworks must provide an integration statement that specifies which actors are provided and in which integration profiles they participate. A sample integration statement is shown in Fig. 6.4.

**Definition 6.19: Technical Framework**

A collection of integration profiles of a given domain.

**Definition 6.20: Connect-a-thon**

A vendor neutral, monitored and controlled, testing event where vendors can test their systems IHE interoperability with other vendors.

**Definition 6.21: IHE Actors**

IHE actors define units of functionality that are required to get a particular job done in a particular integration profile. Note that any given commercial information system may provide no, single or multiple IHE actor functionality.

**Definition 6.22: Integration Profile**

A specific problem of healthcare interoperability AND the details of the standards based, proposed IHE solution.

**Key Concept 6.23: Buying Interoperability**

Purchasers of medical imaging equipment should mandate conformance to the IHE technical frameworks as a contractual obligation of each purchase.
IHE radiology
- The first integration profile developed was **IHE scheduled workflow (SWF)**. It defines precisely how the ADT-patient registration, order placer, order filler, acquisition modality, and image manager/image archive actors must behave in order to acquire imaging studies in an efficient, less error-prone fashion. The technical framework specifies a host of HL7 and DICOM transactions and the order in which they must be executed to acquire a single imaging study.

**Key Concept 6.24:**
**IHE Radiology Integration Profiles**
There are over 20 IHE radiology integration profiles. A successful IIP will monitor the IHE website (www.ihe.net) to stay abreast of yearly developments.

**Thought Problem 6.25: IHE Integration Profiles**
As an example, a CT scanner, as an acquisition modality actor, must perform DICOM modality worklist tasks to identify the patient and the study. It must also perform DICOM storage of the image results as well as DICOM storage commitment so as to transfer responsibility for the study. Lastly, the modality must send DICOM modality performed procedure step instructions to specify exactly the work that was done. Note that DICOM storage often thought to be sufficient is only one-fourth of the work that must be done by the modality.
- The **IHE patient information reconciliation (PIR)** integration identifies the transactions necessary to have smooth operations when information is incomplete. A common scenario is that of the John Doe who arrives at an emergency room. Images are often obtained before the patient is identified and registered and often before orders are placed. An analogous situation occurs when one or more of the information systems are unavailable. PIR describes the transactions necessary to reconcile the systems once the information is available.

- The **nuclear medicine (NM) image** integration profile that defines transactions and the objects they act upon peculiar to the integration of nuclear medicine images into PACS.

- The **mammography image (MAMMO)** integration profile specifies certain details of how digital mammography systems should produce their images and how workstations should display these images to meet the needs of the mammographers.

- The **consistent presentation of images (CPI)** defines how systems shall adhere to **DICOM Part 14**, the grayscale display standard function, so that images displayed on different devices are perceived by the human eye as similarly as possible.

- The **access to radiology (ARI)** integration profile specifies exactly how other systems may query radiology systems for image and non-image information objects.

- The **portable data for imaging** defines how to write CDROMs and other media such that the studies they contain can subsequently be imported into a foreign PACS.

- The **import reconciliation workflow (IRWF)** integration profile is the sister profile to PDI. While writing the CDROM is relatively straightforward, there are several data elements that must be reconciled before import can occur. IRWF specifies these details.

- The **teaching file and clinical trial export (TCE)** is a relatively new integration profile that allows studies to be tagged for export in the clinical setting for use in the research setting. The de-identification is performed by the export manager actor and the studies sent to an export receiver.

- The **radiology audit trail option** defines the way in which each actor can send (for example, HIPAA) required audit transactions to a central server for audit and logging purposes. Note that this profile is now an option on the IT infrastructure domain’s audit trail and node authentication integration profile (since it really belongs in that domain).

- The **cross-enterprise document sharing of images (XDS-I)** integration profile spells out the details of using the IT infrastructure domain’s suite of cross-enterprise document sharing profiles for medical image data sets.
IHE IT infrastructure

- The IT infrastructure group focuses on interoperability problems that span departments in an institution or span across multiple institutions. These so-called horizontal issues would be outside the scope of a more clinically focused domain.
- The IHE IT infrastructure domain has solved several important problems that plague individual institutions: synchronizing time, audit trail, and enterprise user authentication and personnel white pages.
- IHE IT infrastructure is best known, however, for solving the problem of **how to share healthcare information across institutions**.

- A group of healthcare institutions form an affinity domain.
- The affinity domain establishes an IHE patient identity cross-reference manager and implements the **IHE patient identity cross-reference (PIX) integration profile**.
- Document source systems (for example, an electronic medical record or a PACS) send documents (in a variety of standard formats, including HL7 CDA, PDF, and DICOM) to a document repository.
- There can be many repositories in an affinity domain.
- Each repository registers its documents with a single, shared document registry in the affinity domain. These transactions are based on OASIS standards.
- Document consumers wishing to find documents can look up the patient’s shared identity, query the registry for documents related to that patient, and then retrieve documents from the various repositories.
- The XDS-I integration profile describes how to use this infrastructure for sharing DICOM image data sets.
Pearls 6.28

- “The good news about standards is that there are so many to choose from!”
- No single vendor can provide all necessary functionality for a complex environment like healthcare. Therefore, different systems from different vendors must interoperate through the use of standards.
- Standards, themselves, are necessary, but not sufficient for interoperability. The specific details of each standard must be specified and the choreography of when and how the transactions occur must be agreed upon. This is the role of technical frameworks such as IHE.
- Customers should understand the importance of standards and interoperability in their operations and use market forces and purchase contracts to make vendors understand the importance of supporting and implementing standards.
- Standards, while technically complicated, can be understood with only minimal prerequisite information.
- Build the future, participate in standards development!

Suggested Reading


Self-Assessment Questions

1. You would like to know if there is a US standards development organization that specifies how plumbing lines should run through a computed tomography imaging suite. To which organization should you turn to identify US SDOs?

2. You want to learn more about how the Internet and web services work. To which standards development organization should you turn?

3. You notice that one of your systems timestamps is not correct. You need to ask your vendor to turn on software that implements which standard?

4. You are given a DICOM conformance statement by a vendor. To which part of the DICOM standard should you refer to decipher its meaning?
5. You would like to configure a new workstation to perform DICOM query retrieve studies from your PACS. A: What three pieces of information about the PACS will you need to have to configure the workstation? B: What three pieces of information will you need to have to authorize the workstation on the PACS?

6. Your computed radiography systems have just been upgraded and you notice that your PACS workstations are not displaying the images correctly. You are comparing the DICOM headers from the new and old images and notice some difference in the DICOM data elements. To which part of the standard do you need to refer?

7. You are concerned that HL7 order messages are not being communicated successfully between your electronic medical record system and your RIS. To which system should you turn first to investigate this issue?

8. Your vice president of operations asks you to prepare to share images between your institution and a new partner. To which technical framework are you going to refer?

9. Your digital mammography images from Vendor A do not display correctly on the workstation from Vendor B. Where do you look for insight?

10. When shopping for a new healthcare information system, what is the most important document for which to ask?
Chapter 7
Viewing Images

Elizabeth A. Krupinski

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7.1 Introduction

Viewing images is at the core of numerous medical diagnostic tasks, and one can consider it from two perspectives (at least). On the one hand is the technology used to display the images and how factors such as luminance and display noise affect the quality of the image and hence the perception and interpretation of features in that image. On the other hand, there is the human observer relying on their perceptual and cognitive systems to process the information presented to them. This aspect of viewing images is less well understood. From a purely visual perspective, we understand the physiology and basic functioning of the human visual system. What we understand to a lesser degree is how that information gets processed by the higher functioning parts of the brain. How does the radiologist process a set of features in an X-ray image and interpret that as a lung nodule vs. pneumonia? These are issues that are currently under investigation by many medical image perceptionists in their quest to improve reader performance. Traditionally, radiology has been the clinical specialty that utilizes image data the most, but with the advent of telemedicine other clinical specialties within the Integrated Healthcare Enterprise (IHE) are also relying on the interpretation of digital image data for routine patient care. Thus, it becomes important for imaging informatics professionals (IIPs) to understand some of the key issues involved in the image interpretation process and how to optimize the digital reading environment for the effective and efficient image reading.
The purpose of this chapter is to discuss some of the key issues involved in image viewing from the perspective of how to best accommodate the perceptual and cognitive processes of the radiologist (or other clinician) rendering a diagnostic decision. It is important to remember two things when choosing a workstation for daily use in the viewing and interpretation of digital images. The first is that there can be a very daunting task because there are numerous products available on the market and more are continually being added and touted as the “best.” The second is that there is no “one size fits all” workstation that will please every user. In many situations, however, there are established practice guidelines that can provide at least the minimal technical requirements required for digital diagnostic viewing.

7.2 Human Perception Basics

- There are three main aspects of vision that are important for interpreting medical images – spatial resolution, contrast resolution, and color vision.
- The eye is a complex organ, but there are certain parts of this highly specialized organ that deserve a brief description here. The eyes’ main function is photoreception or the process by which light from the environment produces changes in the specialized photoreceptors or nerve cells in the retina called rods and cones. The retina is actually located at the back of the eye, so light travels through the pupil, the lens, and the watery vitreous center before it reaches the retina itself. Within the retina are about 115 million rods and 6.5 million cones. Rods are responsible for sensing contrast, brightness, and motion and are located mostly in the periphery of the retina. The cones are responsible for fine spatial resolution, spatial resolution, and color vision and are located in the fovea and parafoveal regions. The pigments in the rods and cones undergo chemical transformations as light hits them, converting light energy into electrical energy that acts upon the various nerve cells connecting the eye to the optic nerve and subsequent visual pathways that extend to the

Further Reading 7.1


Further Reading 7.2

visual cortices in the brain itself. The fact that we have two eyes accounts for our ability to see depth or for the radiologist to generate the perception of depth from two-dimensional images. The transformation of electrical nerve signals generated in the early stages of vision to the perception of the outside world takes place in a number of brain regions that are equally specialized for visual perception.

- **Spatial resolution**, or the ability to see fine details, is highest at the fovea, but declines quite sharply towards the peripheral regions of the retina. This means that clinicians must search or move the eyes around the image in order to detect lesion features with high-resolution vision. Deficiencies in spatial resolution can easily be corrected by prescription glasses. With age, spatial resolution naturally degrades and most people require corrective lenses. **Glasses specifically designed for computer viewing** can be prescribed and should be considered if a clinician is having trouble viewing softcopy images on digital displays.

### Key Concepts 7.3

The human eye sees details best with the central foveal vision so clinicians need to scan or search images to detect fine or subtle features indicative of abnormalities.

- Visual acuity also depends on **contrast** (and vice-versa) or differences in color and brightness that allows one to distinguish between objects and background in an image. To determine the contrast levels that are perceptible
to the human eye, tests were developed that use a sinusoidal grating pattern (alternating black and white lines where the average luminance remains the same but the contrast between the light and dark areas differs). Discrimination of the grating is described in terms of cycles per degree or the grating frequency. **Contrast sensitivity** peaks in the mid-spatial frequency range around 3–5 cycles/degree. This means that low-contrast lesions can often go undetected, especially when viewing conditions are not optimal.

- Color vision is accomplished by the cones in the retina. There are three types of cones each with a different photopic spectral sensitivity – short, medium, and long wavelengths corresponding to blue, green, and red, respectively. Color vision is less important in radiology than in other medical image-based clinical specialties such as pathology, dermatology, and ophthalmology. Deficiencies in color vision affect about 10% of the population (males more often than females), potentially affecting the interpretation of color and pseudo-color medical images.

### 7.3 Display Hardware Basics

- Technology: **Cathode ray tube** (CRT) displays were prevalent until the start of the 21st Century, but **liquid crystal displays** (LCDs) are now the dominant technology. Most displays in general use as well as in medical imaging are two-dimensional displays in which depth information is only poorly rendered.
  - **Stereoscopic displays** allow for better perception of depth but generally require the use of special glasses to see the depth information. These displays often rely on basic stereoscopic “tricks” to display depth. Two images are acquired of the same object but from slightly (about 15 degrees) different angles. In its most familiar form, one image is coded in red and the other in green. A simple pair of glasses with red and green filters sends one image to one eye and the other image to the other eye. The brain then fuses the images and there is the perception of depth. More sophisticated technologies exist for viewing stereoscopic displays, but they are all based on this basic premise. True 3D displays are available and may be useful for viewing certain types of images, especially 3D and tomographic reconstructions of radiographic images. The technology used in these displays varies depending on the manufacturer. One common technique is to layer the display so that some pixels are in one plane and others in another, woven together in a sense so every other pixel or so is in either the back or forward plane. Once again,
the system relies on the ability of the human brain to fuse the information into a perception of depth although this time without the need for special glasses.

- **Matrix size** or resolution: current displays are typically 1, 2, 3, 4, 5, or 6 megapixels.
  - **Small matrix** (1 or 2 MP) displays are typically used for small matrix radiographic images such as CT, MRI, and ultrasound; clinical (i.e., nondiagnostic or those used by nonradiologists, technologists, clinical staff) review; and nonradiology specialties (e.g., dermatology, ophthalmology).
  - **Large matrix** (3 MP and higher) displays are typically used for digital radiography (e.g., chest, bone); digital mammography; and digital (a.k.a. virtual) pathology. Large displays are really only warranted when the resolution of the displayed images needs the increased resolution. Since these displays are generally more expensive that small matrix displays, their use should be reserved for cases where they are needed (mammography, etc.). The goal when choosing which format to use is to allow for the greatest amount of inherent resolution to be displayed without the use of zoom and pan to access higher resolution data, since zooming and panning result in more time being spent per image and there is the chance that the user may forget to use it or not use it systematically over the entire image.

- **Display pixel size**: display pixel size is a more accurate measure of display resolution. Visual acuity and contrast sensitivity indicate that 2.5 cycles/mm or **200 micron pixel size is best**.

- **Monochrome vs. color**: nearly all displays, both off-the-shelf and medical-grade displays, come in both monochrome and color versions. **Monochrome displays are still recommended for large matrix images** (CR, DR, and digital mammography) because monochrome displays tend to have lower intrinsic noise than color displays. Color displays are often used in radiology for small matrix images such as CT, MRI, and ultrasound. Radiology images that utilize pseudo-color (e.g., 3D reconstructions) should use color displays. Nonradiology medical images such as those from dermatology, pathology, and ophthalmology should all use color displays of the appropriate matrix size.

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**Definition 7.5: MP**

MP refers to “megapixels” or the number of pixels contained in the display.

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**Hypothetical Scenario 7.6: Choosing Display Matrix Size**

Matrix size should be as close to the original acquired image data sent to the display (known in radiology as “for processing”) as possible, or the full-resolution data should be attainable with magnification.
- **Calibration**: display monitors and corresponding video graphics cards must be calibrated to and conform to the current **DICOM grayscale standard display function (GSDF)** perceptual linearization methods. Color displays can also be calibrated to the DICOM GSDF to display monochrome images properly. Methods for color calibration also exist.

- **Display luminance**: ratio of maximum to minimum luminance should be at least 50. Maximum luminance of grayscale monitors used for viewing digital conventional radiographs should be at least **250 cd/m²**. Most manufacturers of medical-grade displays meet this specification. A significant number of off-the-shelf displays meet it as well, but the specifications should be checked before purchasing if the displays are to be used for primary interpretation.

- **Contrast response**: should comply with AAPM Task Group 18 DICOM Grayscale Standard Display Function (GSDF) recommendations and not deviate by more than 10%. Most manufacturers of medical-grade displays meet this specification. Most off-the-shelf displays do not come with the software (or luminance meters) to carry out the DICOM calibration. These items can be purchased separately however and used to calibrate any monitor. The specifications should be checked before purchasing if the displays are to be used for primary interpretation.

- **Bit depth**: minimum of 8-bit depth (luminance resolution) required. Higher is recommended if original or “for presentation” image data are greater than 8-bits in depth. In general, the higher the luminance ratio of the display, the larger the bit-depth resolution that is advised. Most manufacturers of medical-grade and off-the-shelf displays meet this specification. The specifications should be checked before purchasing if the displays are to be used for primary interpretation.

- **Protective shields**: many shields add to reflections and should be avoided.

- **Warm-up time**: to maximize performance, most displays require about 30 minutes of warm-up time.

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**Pearl 7.7**

Most medical-grade displays come with the hardware and software for calibration. Basic hardware can also be purchased for less than $250 and DICOM GSDF test patterns such as the SMPTE monitor test pattern can be downloaded for free. Some vendors also offer remote performance monitoring, calibration, and quality control.

**Hypothetical Scenario 7.8: Meeting Minimal Display Requirements**

A radiologist asks whether an off-the-shelf (nonmedical grade) display can be used for diagnostic reading and whether there are existing guidelines to be followed. The answer is yes – the American College of Radiology (ACR) has published guidelines for Digital Radiology that include display requirements.
7.4 Display Software Considerations

- **Window and level:** Adjustment tools must be available in order to display the full-dynamic range of most images. Presets for window/level can make it easier for users to manipulate images. The idea of window and level is fairly straightforward. Most displays have 4096 shades of gray displayable. However, there are usually only a small range of intensities useful for most studies. Window defines this intensity range and defines the upper and lower shades to be included in the “window.” The rest of the pixels that the user is not interested in for that particular view of the image, are either mapped to black or white. Level is a related technique. It is a mathematical definition of how to map pixel values in the window to display luminances. For example, suppose someone wants to see a detail in a very dense tissue area. They could select a level that transforms an intensity difference of 1 to a luminance difference of 5 when displayed. In other words, if two dots in an image have pixel intensities of 125 and 126, the human eye cannot discern them from each other. By leveling or stretching them and increasing the luminance difference to 5, the difference is easily seen and a subtle feature becomes obvious.

- **Zoom and pan:** magnification and roaming should be used to display the originally acquired image spatial resolutions. Users should not move closer to the display.

- **Image processing:** five generic processing tools fulfill most image processing needs.
  - grayscale rendition
  - exposure recognition
  - edge restoration
  - noise reduction
  - contrast enhancement.

- **Image rotation:** tools for image rotation and flipping are essential.

- **Hanging protocols:** automated tools for image sequencing and preferred display format should be available, flexible, and tailored to user preferences.

- **Response time:** the time needed to display an image stored locally (as opposed to a long-term archive) should be 3 seconds or less.

- **Data tagging:** automated tools that accurately associate patient and study demographic information with the images is essential.

- **Measurement tools:** tools that calculate and display linear measurements with appropriate units, regions of interest, and pixel values (mean and standard deviation) are useful.

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**Pearl 7.9**

When deciding what vendor to use for purchasing diagnostic workstations, it is ideal to have multiple vendors come to your site on the same day for a “shoot out” during which you can compare and use products side-by-side. An alternative strategy is to attend a conference with an exhibition area where multiple vendors are present.
- **Image compression:** if compression is applied to an image or set of images, the type (encoding method such as JPEG, and lossy vs. lossless) and amount (e.g., 10:1) should be known.

- **Total image set:** all images acquired in a study need to be accessible for interpretation. It is not necessary to display them simultaneously, but the use of dual monitors to display multiple images at full resolution is useful.

- **Acquisition parameters:** clinically useful technical parameters of the acquired image should be accessible (e.g., mAs, kV, exposure value).

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**Definition 7.10: Compression**

Compression reduces the volume of data to reduce image processing, transmission times, bandwidth requirements, and storage needs.

*Lossless compression* allows for reconstruction of exact original data before compression without loss of information.

*Lossy compression* uses methods that lose data once the image has been compressed and uncompressed.

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### 7.5 Human–Computer Interface

Workstation technologies (hardware and software) impact diagnostic accuracy, visual search, and interpretation efficiency. Hardware and software optimization techniques are often derived in part by considering the capabilities of the human visual system, especially with respect to spatial and contrast sensitivity. There are also factors related to the environment in which the workstation will be placed and how the clinician interacts with the technology that are important. Poor interface and environment can reduce diagnostic accuracy, reduce reader efficiency, and increase reader fatigue and possibly injury. Ergonomics should be considered in the digital reading room.

- **Ambient room lights:** ambient light sources should be kept at a minimum to reduce reflections and glare. Indirect and backlight incandescent lights with dimmer switches rather than fluorescent are optimal. Clinicians should avoid wearing light-colored clothing and lab coats since they add to reflections and glare. About 20–40 lux (or 0.03–0.06 Watts using yellow wavelength which the eyes are most sensitive to, conversion varies as a function of wavelength) will avoid reflections and still provide sufficient light for the human visual system to adapt to the surrounding environment and the displays. Room lights should not be turned off completely.

- **Viewing direction:** users should be seated as close to on-axis viewing as possible since some displays suffer from poor viewing angles and image contrast degrades as the viewer moves off-axis. If dual displays are used they should be placed side-by-side and angled slightly in towards each other.
- **Ambient air:** computers, especially with dual monitors and in rooms with multiple workstations, require adequate air flow, optimal temperature, and humidity controls. Direct ventilation for each workstation may be needed and water-cooled computers should be considered if extra cooling is required.

- **Ambient noise:** noise can distract the clinician from the diagnostic task so it should be minimized. Movable walls, sound-absorbing tiles/walls, and carpeting can be used to minimize noise between workstation areas. If dictation systems are used, it is especially important to isolate users from each other.

- **Seating:** chairs with good lumbar support and **adjustable height controls** can help avoid injuries and fatigue.

- **Desk/tabletops:** it should be possible to adjust the height of tables and/or desks for each user.

- **Peripheral input devices:** keyboards and mice should be comfortable for each user and placed for ease and comfort during use to avoid hand and wrist injuries. Dictation tools, Internet access, and other reference tools should be readily accessible and easy to use during image interpretation.

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**Our Experience 7.11:**

**Computer Vision Syndrome**

With the switch from hardcopy film to softcopy digital reading in radiology, radiologists are spending long hours in front of computers doing “near reading.” Long hours of near reading off computers can lead to Computer Vision Syndrome characterized by blurred vision, double vision, dry eyes, the inability to focus properly, and headaches. We measured radiologists’ ability to focus properly (or accommodate) on a target at the beginning of the day before reading images and after a long day of continual softcopy image reading. We found that there was more error in accommodation after a day of reading than before, especially for targets closer to the eyes. If radiologists are having difficulty focusing on discrete targets, this could lead to increased errors as a function of reader fatigue.
Pearls 7.12

- The solution to some complaints about image and/or display quality could be an eye exam and prescription for corrective lenses.
- Most medical-grade displays come with the hardware and software for calibration. Basic hardware can also be purchased for less than $250 and DICOM GSDF test patterns such as the SMPTE monitor test pattern can be downloaded for free.
- When deciding what vendor to use for purchasing diagnostic workstations, it is ideal to have multiple vendors come to your site to compare products side-by-side.

Suggested Reading


Self-Assessment Questions

1. Lossy data compression does all but which of the following?
   a. Allows for storage of more data compared to no compression.
   b. Loses data once the images have been compressed and uncompressed.
   c. Slows down transmission of image data over networks.
   d. Allows for reconstruction of exact original data as before compression without loss of information.
2. Three of the key visual properties important for the interpretation of medical images are
   a. Contrast resolution, spatial resolution, and the color of the eyes.
   b. Night vision, contrast resolution, and spatial resolution.
   c. Color vision, spatial resolution, and blink rate.
   d. Spatial resolution, contrast resolution, and color vision.

3. Display pixel size is a more accurate measure of display resolution and should be what size?
   a. 50 microns
   b. 100 microns
   c. 200 microns
   d. 300 microns

4. Monochrome displays for diagnostic viewing and interpretation of images should be calibrated to what standard?
   a. DICOM gray scale standard display function
   b. HDTV display standards
   c. SMPTE display standard

5. Ambient room lights should be indirect or backlight and set to what level?
   a. Turned off completely
   b. 40–60 lux
   c. 20–40 lux
   d. 0–20 lux

6. Small matrix (1 or 2 MP) are appropriate for all of the following types of images except what kind?
   a. CT
   b. Digital mammography
   c. MRI
   d. Ultrasound

7. Contrast sensitivity peaks in the mid-spatial frequency range around 3–5 cycles/degree and is important for what aspect of image viewing?
   a. Distinguishing between objects and background in an image.
   b. Measuring the size of an abnormality.
   c. Distinguishing blue stained cells in a pathology slide from red stained cells.
   d. Detecting fine features in an image.
8. The ratio of maximum to minimum luminance of a display should be at least
   a. 25
   b. 50
   c. 75
   d. 100

9. List some of the major ergonomic factors one should consider when setting up a digital reading room.

10. List some of the important software capabilities one should consider and evaluate when purchasing display software for a workstation.
Chapter 8
Image Postprocessing and Volume Rendering

Daniel Blezek, Xiaojiang Yang, and Bradley J. Erickson

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8.1 Introduction

Nearly all images produced in a medical imaging department are processed to some degree. Some processing is done to make digital images look more like their film predecessors. Some processing is done to accentuate certain features (e.g., bone and soft tissue kernels in CT) or to provide higher resolution (e.g., MRA). This postprocessing is typically focused on producing images that are visually pleasing. However, postprocessing can also be used to improve the performance of a CAD algorithm, to produce renderings of components of the image set that are more useful. This chapter will begin with very basic image
processing functions, and proceed on to advanced techniques that are increasingly being applied as a part of postprocessing enhancements.

### 8.2 Image Filtering

#### 8.2.1 Histogram Manipulation

- **Standard window/level manipulation** may be considered manipulation of the histogram of an image. Reducing the window width increases contrast, while wider windows reduce contrast. Standard window/level settings for CT include head (100/40), lung (1500, −750), soft tissue (400/40), and bone (2500/300). Figure 8.1 shows examples of window level applied to the CT images of the abdomen.

- Histograms may also be matched between images to produce similar contrast between images from different studies. This technique is useful for visual comparison across patients in MR exams (Fig. 8.2).

#### Definition 8.1: Histogram

A graph that reflects how many pixels of each brightness are on the image. The horizontal axis is brightness, and the vertical axis is the number of pixels.

### 8.2.2 Enhancement

Many enhancement methods exist. Two commonly used in medical imaging are

- **Unsharp mask filters** may be applied to images to bring out features of details. Unsharp masking is a standard enhancement filter that selectively subtracts...
a blurred image from the original. Pixels in the blurred image that differ from the original by an amount more than a user-specified threshold are considered to be “masked.” Any pixel under the mask is subtracted from the original, otherwise the pixel is unmodified.

- **Edge sharpening filters** selectively enhance edges in the image based on edge strength. These filters are demonstrated in Fig. 8.3.

**8.2.3 Frequency Filtering**

- Images may be decomposed into a collection of frequencies by the **Fourier transform**. Multiplication in the Fourier domain is equivalent to convolution in the image domain. Thus, all Fourier domain filters have equivalent convolution-based filters in the image domains. When convolution-based filters become too big, they are more efficiently implemented in the Fourier domain. Although difficult to understand and interpret, the Fourier transform is very useful for image processing and analysis. Examples are shown in Fig. 8.4.

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**Key Concept 8.2: Enhancement**

When radiologists say “enhancement,” they are usually talking about an intravenous injection of material that makes vascular tissues more visible. But, in the context of image postprocessing, enhancement refers to any method that makes particular elements in the image more visible.

**Definition 8.3: Convolution**

The multiplication of a neighborhood of pixels by a “kernel.” Each value in the kernel is the number by which the corresponding neighborhood pixel is multiplied. If all the values in the kernel are “1,” the result is the mean.
8.2.4 Noise Reduction

Noise is present in all medical images. We can reduce the amount of noise by increasing radiation dose (for X-ray methods) or increasing field strength or imaging time (MR). Image processing also offers ways to reduce noise, but sometimes at the cost of introducing artifacts.

- The simplest filter for noise reduction is averaging, sometimes called block filtering. Each pixel is replaced by the average of its neighbors. The filter considers neighboring pixels with a user-specified radius. A radius of 1 is a
3 × 3 block of pixels, centered at the output pixel. Examples of this filter and others are shown in Fig. 8.5.

- **Slightly more complex is the Gaussian filter.** Unlike the averaging filter, the contribution of neighborhood pixels is weighted by their distance from the output pixel. Gaussian filtering blurs the image, and is equivalent to low-pass filtering using a Gaussian in the Fourier domain. Gaussian filters are classified by their width or sigma.

- **Median filtering** considers a patch of neighborhood pixels. The intensities in the patch are sorted, and the median value is chosen in the output. Median filters are simple and efficient noise reduction filters with good performance. They exhibit less blurring than averaging and Gaussian filters.

- **Anisotropic diffusion filtering** smoothes regions without strong edges while preserving edges. This filter iteratively solves the solution to a partial differential equation modeling heat flow. The smoothing caused by the “heat” does not flow across regions of large image changes or gradients. This filter has several parameters controlling the rate of heat flow and the amount of smoothing to apply.

- **Bilateral filtering** is a recently developed method similar to the Gaussian filter. In setting weights for a pixel in the neighborhood, both spatial distance and intensity distance. Near an edge, neighborhood pixels will have a large

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**Definition 8.5: Filter**

A processing method that enhances or removes a specific component in a signal or image. The name could reflect what is removed, what is enhanced, or the calculation that is used.

**Definition 8.6: Noise**

Random fluctuations in the image information that can obscure the true elements in the image. Noise reduction is also called improving the signal-to-noise ratio.
difference ("intensity distance") from the output pixel and have a smaller weight. Bilateral filtering produces results similar to anisotropic diffusion without iteration and is the better choice.

- The nonlocal means filter is also a newer technique that examines a "patch" centered about each pixel. The output pixel is a weighted average of center pixels from patches in a user-specified search region. Patches of similar contrast and intensity are more heavily weighted. The idea behind nonlocal means is that similar patches, when averaged, will wash out noise. Patch size and search region influence the quality of results and processing time.

### 8.2.5 Practical Considerations

- Though sometimes used for display, filtering is often used as a preprocessing step for segmentation, classification, and computer-aided diagnosis. Many algorithms do not consider effects of noise, and produce better results on preprocessed images.
- Filters may be applied on each slice of an acquisition independently, or may be applied in a 3D mode, incorporating pixel information from neighboring slices. For thick slices, 3D filtering may cause unwanted artifacts. In general, 3D filters are much slower than single-slice filtering.
- Simple filters such as averaging, Gaussian, and median are generally implemented as kernel operations sliding over each pixel in the image. On modern workstations, these filters operate nearly in real time. In contrast, better noise reduction can be obtained with more complex filters such as the anisotropic, bilateral, and nonlocal means filters, but at the expense of more computation time. Complex filters can be applied in batch and stored in PACS as secondary capture series.

### 8.3 Segmentation

Segmentation is an essential step if one wishes to perform automated measurements on organs or diseases.

#### 8.3.1 Basics

- The most basic and fundamental segmentation algorithm is **global thresholding**. A pixel is considered foreground if its intensity is higher than the threshold value or background if lower. Bones in CT images are easily segmented with thresholding, though contrast material and calcifications...
may sometimes be included in the foreground. Thresholding is shown in Fig. 8.6.

- The Otsu algorithm automatically determines a threshold such that the foreground and background have low variation in intensity, and are as widely separated as possible. In CT images, the Otsu algorithm reliably segments tissue from air.

- To segment individual objects, a set of “seed pixels” is selected. Each neighboring pixel is classified as foreground or background based on some criteria, usually intensity value. The neighbors of the neighbors are checked, and the process of “region growing” continues until no new neighbors meet the inclusion criteria. Region growing is used to interactively segment organs.

8.3.2 Morphological Operators

- Morphological image filtering is the theory and technique for processing of geometrical structures as applied to image. While morphological operators may be applied to grayscale images, they are most often applied to binary images.

- The structuring element probes the image with a shape, deciding how the shape fits or misses the shapes in the image. “Square” and “jack” are common shapes for structuring elements. Specialized structuring elements may be constructed for specialized processing. Examples of the square and jack structuring elements are shown in Fig. 8.7.

- Two basic operations are erosion and dilation. Erosion can be thought of as moving the structuring element around the inside of the segmented region. Border pixels are “eroded” away from the border to where the structuring element completely fits within the object. Dilation is best thought of as moving the structuring element around the outside of the segmented object, making the object bigger (dilating) by adding the center voxel of the structuring element anytime it touches a voxel in the segmented region. The effects of dilation and erosion on an object depend heavily on the structuring element chosen as is seen in Fig. 8.7.

- Generally, segmentations generated using thresholding or region growing contain “holes,” regions, or voxels outside the intensity range. Holes may be
filled using a combination of erosion and dilation called **closing**. Dilation is applied first, followed by erosion. This has the effect of filling small holes in the segmentation and smoothing the border region. **“Opening”** applies erosion followed by dilation to enlarge holes in the segmentation.

### 8.3.3 Classification

- In contrast to segmentation, classification algorithms assign a voxel to one or more “classes” of tissue. (Segmentation can be seen as classification with two classes: object and background.)
- **Multispectral classification** utilizes data from two or more images of the same anatomy to assign class labels to voxels. A common example is using T1- and T2-weighted MRI scans to distinguish white matter and gray matter. Such schemes can be augmented with **prior probabilities**. Prior information is often spatial, indicating the frequency at which a voxel is white matter or gray matter. This information is compiled from a population into an **atlas**. For example, a well-known atlas of neuroanatomy is available in the Statistical Parametric Mapping (SPM) package (http://www.fil.ion.ucl.ac.uk/spm/).

### Definition 8.8: Classification

**The assignment of a meaningful name like “lung” to a group of pixels or voxels.**

### 8.4 Registration

- Registration may be intra-subject (within the same subject), inter-subject (across different subjects), intra-modality (using images from one modality), and/or inter-modality (using images from multiple modalities). Algorithms for
registration are loosely classified by transforms allowed, similarity metric, and minimization. To register two images, a minimization algorithm tries different transformations and evaluates each of these transformations using a similarity metric. The minimization process tries to find the global minimum of similarity metric, the transformation at that minimum should bring the two images into alignment. This process is graphically shown in Fig. 8.8. The moving image is transformed by rigid transformation onto a fixed image. The metric used is a squared difference metric. Figure 8.8 shows the initial difference and the final difference. Difference images are useful ways to evaluate registration results for images of the same modality. An overview of the registration process is shown in Fig. 8.8.

**Definition 8.9: Registration**
The process of aligning images with one another. This means that the same tissue sample exists at a given X, Y, Z location on all registered images.

**8.4.1 Transforms**

- Transformations generally have one or more parameters. The number of parameters for transform is referred to as the dimension of the transform. For example, for a simple rigid 2D, there is one rotation and two translation parameters. Simple transformations generally have fewer parameters, while more complex or deformable transformations have many parameters.
- **Rigid-body transforms** allow rotation and translation, but not scale or deformation. In 3D, there are three rotations and three translation parameters comprising a six-dimensional space. Rigid-body transformations are used in neuroimaging. Patients are often imaged in different positions and rigid-body transforms are used to align images acquired at different times to aid radiologic interpretation.

**Definition 8.10: Transform**
A mapping from the space of one image to the space of another image.
• **Affine transforms** add scaling and shearing to rigid-body transforms and are useful for inter-subject registration. Often, registration using an affine transform is used as input to high-dimensional deformable transformation registration. Affine transforms are 12 dimensional transforms.

• **Deformable transformations** are often called high-dimensional transforms and allow many possible deformations of one image into another. Deformable transforms are applied inter-subject (mapping subjects to one another), and intra-subject in regions of high motility, e.g., abdomen, lungs, or after surgery that changes shape of anatomic features. For each continuous point in one image, a deformation may be calculated and applied to move the point onto the corresponding point in the second image. Deformable transformations may be classified by the type of kernel or basis used, e.g., B-spline, thin-plate-spline, cosine, etc.

### 8.4.2 Similarity Metrics

• Similarity metrics quantitatively score the “goodness-of-fit” of two images related by a transformation. The score produced by a similarity metric indicates how well the images are aligned with a lower score indicating a better agreement between the two images. A similarity metric with an analytic gradient allows optimizers (discussed in the next section) to rapidly find a global minimum. Metrics without analytic gradients may also be used in optimizers but the gradients must be found numerically.

• One of the most basic similarity metrics is **mean-squared differences**. The goodness-of-fit in the mean-squared differences metric is measured by the summation of the squared differences between the two images. This metric requires the images to be from the same patient in the same modality. It is computationally challenging because each voxel in the image must be used in the calculation.

• The **normalized correlation** similarity metric is independent of contrast differences in the two images and may be used cross-modality. Normalized correlation is also computationally demanding.

• Statistic-based similarity metrics do not require each voxel in the image to be used in the computation but rather take a statistical sampling of the voxel set.

---

**Key Concept 8.11: Rigid Transforms**

Rigid image registration is useful for images of structures that do not deform substantially – e.g., the brain. It does not work well for structures that move, like the small bowel.

**Definition 8.12: Similarity Metrics**

Quantitative measures of how well two images are matched. They are an essential element of image registration.
Most statistical metrics are based on image entropy. Entropy is the measure of information content in a signal, the joint entropy between two images is used as a similarity metric. This is known as mutual information, and is the most common statistical similarity metric.

### 8.4.3 Optimization

- Optimization is a very active area of research in the medical imaging community. Optimization is also very difficult problem, and solutions that work in one imaging domain may not work in another. An optimization algorithm tries to find a global solution to an energy function. The similarity metrics and the parameters to the transformation are what the optimization algorithm is modifying an attempt to find a global solution.

- A simple optimization algorithm is **gradient descent**. The gradient descent algorithm begins with a certain set of transformation parameters and using the analytic gradient of the similarity metric with respect to the transformation parameters follows the gradient down to the global minimum. Gradient descent is susceptible to local minima where a less than optimal solution is found.

- If analytic gradients cannot be computed for similarity metric, a **line search algorithm** such as Powell optimizer is useful. Each parameter of the transform is optimized in turn in a greedy fashion. In a greedy algorithm, one parameter is changed, until a local minima is found, then the next parameter is changed until all have been optimized in turn.

- For high-dimensional transformations, **statistical optimization algorithms** are effective at finding global minima. A statistical optimization algorithm attempts to find a local gradient at a given transformation by probing in random directions in the parameter search space.

---

**Hypothetical Scenario 8.13: Image Postprocessing**

Describe a sequence of steps for improving the quality of MIP renderings of MRA data for intracranial vessels.

Possible answer:

1. Apply a noise reduction filter like a nonlocal means filter.
2. Compute the histogram, and find the peak representing brain. Do this by finding the biggest peak which is above air (air intensity is found by sampling image corners).
3. Segment the image into vessels by setting a threshold above brain intensity. Have this image be binary – “1” or “0.”
4. Multiply this “mask” with the original image so that nonvessels have 0 intensity, while vessels have original MRA intensity.
5. Render the MRA.
8.5 3D Visualization

Modern medical modalities such as CT and MRI generate large amount of 3D volumetric data in the form of 2D slices. Postprocessing techniques, including volume rendering, allow these data to be displayed in a variety of useful ways.

- **Projection rendering** is the simplest and fastest volume rendering method, and maximum intensity projection (MIP) is a commonly used example. Though commonly used, MIPs do not have depth information and may obscure important structures.

- Another option is to extract the surface of interesting object(s) and then render accordingly. Shading technology is used in this technique, generating a shaded surface display (SSD). Different shading models may be used, resulting in different appearances. Surface rendering can be very fast and can take advantage of widely available rendering hardware. One shortcoming of it is that the SSD image does not provide any inside view of the object(s), which is essential to users in some situations. Besides this, surface rendering requires segmentation (see previous section) that can be labor intensive and error-prone.

- **Direct volume rendering** renders images of 3D volume data sets directly from the 3D volume data without extracting any geometrical information about the objects captured. When rendering a data set, optical properties (color and opacity) are accumulated along each viewing ray. The optical properties are specified by using transfer functions that are applied to the volume data.

### 8.5.1 Volume Data and Its Grid Structure

- In medical imaging, 3D volume data are usually in a rectangular format grid, consisting of multiple “slices,” where each slice often has a dimension of 512 × 512 or 256 × 256. While each 2D image slice is generally isotropic (in 2D coordinate system), the whole 3D volume data are generally anisotropic (in 3D coordinate system).

- Resampling the data to produce isotropic voxels before volume rendering is optional, but maybe useful.
8.5.2 Projection Rendering

Multi-planar Reconstruction (MPR)

- MPR is the reconstruction of images in arbitrary orientations such as orthogonal, oblique, or even curved plane. This method allows real-time viewers to slide through a given volume in any directions.
- The common application is creating coronal and sagittal reformatted images from axial data sets.
- MPR can sometimes provide better demonstration and additional diagnostic information, particularly in the evaluation of complex anatomical structures or areas that are traditionally difficult to evaluate on axial images.

Maximum Intensity Projection (MIP)

- MIP is the projection of voxels with highest intensity onto an arbitrarily oriented plane. MIP is commonly used in angiography to extract vascular structures from CT or MRI data sets.

Minimum Intensity Projection (MinIP)

- In contrast to MIP, MinIP is the projection of voxels with lowest intensity onto an arbitrary plane. At each voxel along a viewing ray, the lowest data value encountered is recorded.
- MinIP is often used for rendering lungs and airways.

Pearl 8.17: MIP & MinIP

- The drawback of MIP and MinIP images is the lack of depth information. As a result, some objects lying in the same projection plane of high- or low-intensity structures might be invisible.
- Both MIP and MinIP can be regarded as a simplified volume ray casting algorithm, and thus a form of direct volume rendering.

8.5.3 Surface Rendering

- Surface rendering, also known as shaded surface display (SSD), refers to a class of techniques that use surface primitives (or patches) such as polygons (typically triangles) to fit the isosurface inside a volume data, and then use shading models to render the surface. Surface rendering treats the object inside a volume as having a surface of a uniform value.
- Before the isosurface is fitted, segmentation algorithms may be optionally used to extract the structure or mask of the interested object. By doing segmentation, unwanted overlying structures can be eliminated, and fitting process can also be simplified.
• After the isosurface is fitted, we calculate the normal at each patch’s vertex by interpolating the gradient at voxels (refer to the D Direct Volume Rendering for details). Normals are then used in the shading process. Three most commonly used shading models are Constant, Gouraud, and Phong.

• Surface-rendered images look like pictures of three-dimensional **solid objects**.

• **Marching Cubes** is a famous algorithm for building polygonal (triangular) patches of an isosurface from a 3D volume. The algorithm assumes that, with the specified value, there is a continuous isosurface inside the volume.

• Shading models are used to describe how light interacts with objects and reflects to our eyes. Shading models include models of illumination. **Phong illumination model** is the most widely used illumination model. All shading models, such as Constant and Gouraud, are based on the Phong illumination model.

### 8.5.4 Direct Volume Rendering

• There are two classes of direct volume rendering techniques: image-order (or image-based) techniques and object-order (or object-based) techniques.
  - **Image-order techniques** use rays casting from some point (e.g., human eye) through each pixel in the result image to the 3D volume data, resampling points along the ray from the volume data, and compositing the contribution of each resampling point in each ray as the resulting pixel.
  - **Object-order techniques** compute the projection and contribution of each voxel in 3D volume data set to the pixels in the image plane.

• A typical **pipeline** of direct volume rendering includes the following operations: segmentation, gradient computation, resampling, classification, shading, and compositing. Different algorithms and implementations may have more or less operations, as well as their sequence.
  - The gradient is the normal of the local surface near a resampling point to calculate diffuse reflection and specular reflection of lights.

---

**Further Reading 8.18: Marching Cubes**

- Open source implementation using VTK. Available at: [http://www.vtk.org](http://www.vtk.org).

**Definition 8.19: Pipeline**

A sequence of stages that performs a task in several steps, like an assembly line in a factory. Each stage takes inputs and produces outputs that are stored in its output buffer. One stage’s output is the next stage’s input.
There are several ways to approximate gradient in a discrete 3D volume. Central difference approach and intermediate difference approach are most common ones.

Central difference approach is popular because it also smoothes noise that often results in quite good looking pictures. However, intermediate differences are more accurate and therefore preserve more details.

As imaginary rays pass through the block of voxels, samples will be taken along each ray for accumulation. Because these sample points are seldom located exactly in the voxel locations, interpolation is needed to get the desired sample according to the voxels surrounding it. This process is called resampling or interpolation. Resampling is a computationally intensive work – if too much resampling is needed, it can greatly decrease the performance of the rendering algorithms.

The classification stage in the volume rendering allows you to see inside of an object in a volume without explicitly define the shape and boundary of that object. This is one of the main advantages of direct volume rendering over surface volume rendering. A special property, called opacity (or alpha), is assigned to each voxel in the volume.

In the shading stage, a first step called coloring is executed. Coloring is the process of assigning colors to voxels. This is realized by a function called color transfer function. The second step in the shading stage is to apply a shading model to the colors. Since most medical modalities only generate gray-level image data sets, shading is very useful in enhancing the realism of the image.

Compositing is the process to accumulate multiple RGBA (short of RGB and alpha, where R = red, G = green, B = blue, and Alpha = transparency) value pairs calculated along a specific ray to one single RGBA value pair representing a pixel in the resulting image. After a composition is done for all possible rays, the final image is formed.

Two popular configurations of the volume rendering pipeline exist: preshaded configuration, in which classification and shading are done for all voxels firstly, and then interpolations are implemented for the resulting RGBA values down to the sample points on a ray; postshaded configuration, in which interpolations are executed firstly for gradient and intensity values down to the sample points on the ray, and then classification and shading are performed on the sample points.

Based on the two configurations, three important volume rendering methods exist: volume ray casting, splatting, and Shear-Warp. It is important to note that each of these methods has many variations when they are implemented.
- **Volume ray casting** is a class of image-order volume rendering techniques that can provide results of very high quality at the price of long runtime.

- **Splatting** is a class of algorithms that computes the contribution of a voxel to the image by convolving the voxel with a reconstruction kernel that distributes the voxel’s value to a neighborhood of the pixel. The distribution area and data are called the footprint of the voxel. Because there is no resampling and interpolation process, the splatting algorithm is faster than the ray casting algorithm, but it generally suffers from lower rendering quality.

- The **Shear-Warp algorithm** combines the advantages of both image-order algorithms and object-order algorithms and is considered to be the fastest of the three methods. The core idea of the Shear-Warp algorithm is the introduction of an intermediate object space, called sheared object space. Volume data are first resampled and transformed to this space, where simple ray casting method is then applied (Fig. 8.9).

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**Key Concept 8.21: Volume Ray Casting**

Volume ray casting, also called ray casting for brevity, is an image-based volume rendering technique. It computes 2D images from a 3D volumetric data set by casting an imaginary ray from some point (human’s eye, for example) to the volume. Volume ray casting, which processes volume data, must not be confused with the traditional concept of ray casting found in computer graphics, which processes surface data only.

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**Further Reading 8.22: Splatting**


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**Further Reading 8.23: Shear-Warp**

Pearls 8.24

- Image filtering reduces noise in images, while preserving edge information. Image filtering may be used as a preprocessing step or in real time during imaging.
- Segmentation is the process of identifying regions of interest within an image and is often used for quantification of size and shape of structures. Morphological operators are often used to “clean up” segmentations, filling in holes, and breaking small bridges between structures.
- Registration algorithms are composed of transformations, similarity metrics, and optimization of algorithms. Registration is useful for comparing studies through time and is easily applied in their own imaging and more difficult and body imaging.
- Volume rendering is a visualization technique to display a 2D image of a full 3D data set.
- MIP and MinIP are the simplest and fastest volume rendering method.
- Direct volume rendering can give users details of the object(s) inside a volume, whereas surface rendering shows only the exterior of objects.

Suggested Reading

Self-Assessment Questions

1. Which of the following is an advanced de-noising algorithm?
   a. Averaging filter
   b. Nonlocal means
   c. Gaussian filter
   d. Median filter

2. Morphological filtering is commonly used for?
   a. registration
   b. de-noising
   c. “cleaning up” segmentation
   d. image display

3. Which of the following filters may be applied in real time (before all images are acquired)?
   a. averaging
   b. Nonlocal means
   c. Gaussian
   d. Anisotropic diffusion

4. In a registration algorithm, the metric is used to
   a. filter the images
   b. find the global minimum
   c. segment the images
   d. determine if the images are in alignment

5. Which registration transform is suitable for neuro-imaging registration?
   a. Thin-plate spline
   b. Affine transformation
   c. Rigid-body transformation

6. Which of the following is NOT a direct volume rendering technique?
   a. MIP
   b. Marching Cubes
   c. Volume ray casting
   d. Splatting
   e. Shear-Warp

7. To simultaneously render more than one object in a volume, which of the following volume rendering technique will lead to the best rendering quality?
   a. MIP
   b. SSD
c. Volume ray casting
d. Splatting
e. Shear-Warp

8. Describe situations in which MIP is preferable to MinIP.
9. Describe situations in which MinIP is preferable to MIP.
Chapter 9
Image Distribution

Paul J. Chang

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9.1 Introduction

Implementing a PACS within the radiology department is relatively straightforward; current vendor offerings work reasonably well with respect to image delivery to the traditional reading room. However, radiologists are not the only medical personnel who view (or create) images. Efficient mechanisms for the ubiquitous distribution of digital images throughout the health-care enterprise are essential to realize the most important benefits of the PACS. These benefits include the substantial cost savings when one no longer has to print and deliver film throughout the enterprise as well as the presumed improvement in patient care when health-care providers throughout the enterprise have immediate access to medical images.

Unfortunately, the distribution of digital images to the radiology reading room is relatively “simple” when compared to delivering these images throughout the enterprise. Image distribution within the radiology department usually involves a limited number of modalities and reading rooms with a small number
of workstations. “Brute force” approaches using high-bandwidth networks and “heavy iron” workstations can be used when dealing with a few reading rooms. In addition, the radiologist’s workflow is relatively straightforward and predictable when compared to other health-care providers.

Unfortunately, these “radiology centric” approaches cannot be applied economically to address the needs of the enterprise image consumer. Deploying the expensive network and workstation infrastructure commonly used within the radiology department throughout the enterprise would not be feasible economically: the majority of enterprise image users will be using relatively modest personal computer/web clients with “standard” network connectivity. Although the enterprise image consumer will be using “less capable” IT infrastructure, their functional and workflow requirements are frequently more demanding than those of the radiologist, especially with respect to ad hoc image delivery, integration with the electronic health record (EHR), and security.

This chapter is a practical guide to help you implement an effective enterprise image distribution strategy.

9.2 Functional Requirements and Technology Strategies

9.2.1 Functional Requirements

- **Flexibility** (*one size does not fit all*): must provide for the needs of a wide variety of users, including those who require full fidelity/diagnostic images. One must get early and constant input from all types of enterprise image consumers when designing and implementing an enterprise image distribution strategy.
  - User types
    - **“Non-critical users”**
      - Those who only occasionally require access to images.
      - Usually do not make patient management decisions based on their interpretation of the image. Typically depend more on the radiologist’s report rather than the images alone.
      - Usually do not demand or require full fidelity/diagnostic-quality images. Emphasis should be on rapid (“near real time”) delivery of images and ease of use of web-image viewer client.
      - Frequently access images through web client instantiated through the EHR, using some context sharing integration approach, such as vendor application programming interface (API), web service, or CCOW.
– Usually can leverage existing network and personal computer infrastructure, including “off the shelf” monitors without significant issues.
– Example users: family practice, pediatrics, general internal medicine, other primary care providers.

• “Image-intensive users”
  – Frequently make patient management decisions based on their interpretation of the image.
  – Frequently demand and require full-fidelity/diagnostic-quality images.
  – Also demand rapid (“near real time”) delivery of images, including relevant priors.
  – Usually still constrained by existing network and personal computer infrastructure. If web client is to be used, must serve as an acceptable proxy for diagnostic workstation. These users must be consulted early and often when planning and implementing image distribution.
  – May require use of diagnostic-quality monitors.
  – Example users: orthopedics, neurosurgery/neurology, pulmonology, emergency medicine, intensive care, OR.

• **Performance**: enterprise image consumers can be even more demanding with respect to image delivery performance.
  – Radiologist workflow: even when “on demand” image delivery is not available, strategies such as auto-routing and prefetching can be used due to the highly predictable nature of radiology workflow (e.g., “auto-route the abdominal exams to the abdominal reading room workstations and prefetch the relevant priors to the same abdominal reading room workstations”). Even if these strategies occasionally fail, there is usually no great impact if images (or relevant prior exams) are not immediately available: the radiologist simply “goes on to the next case” without significant negative impact on efficiency.
Enterprise user workflow

- Usually cannot “go onto the next patient” if images are not immediately available.
- Frequently cannot predict the user’s physical location. Cannot predict what particular images will be required. Makes auto-routing and prefetching untenable. Requires “on-demand” delivery model.
- Requires “near real time” delivery of images, including relevant priors.

Scalability: must be able to provide high performance ubiquitous distribution of images throughout the entire enterprise (and beyond).
- Must support potentially many simultaneous users.
- Must support users “outside the firewall” (WAN, Internet).
- Must have acceptable functionality even with the performance overhead of security protocols (e.g., HTTPS, VPN).

Cost-effectiveness: must be able to provide services leveraging usually limited infrastructure (network, including wireless) and modest clients (PCs).

Image visualization, navigation, and manipulation: must be “optimized” for a particular user, not “crippled.” Ease of use cannot be achieved by sacrificing required functionality.

Integration into the EHR: usually not too difficult. The majority of vendors offer some context sharing integration approach, such as vendor application programming interface (API), web service, or clinical context object workgroup (CCOW).

Security: enterprise availability of images can present security challenges. Common approaches incorporate VPN strategies; HTTPS can be used if supported by web client. HIPAA requires audit of these enterprise users when accessing patient image data; the majority of vendors provide this functionality.

Definition 9.4: Autorouting

The automatic transmission (“routing”) of image datasets from the modalities to remote destinations based on predefined rules (e.g., “autoroute all abdomen CT exams to the abdomen reading room workstations”).

Definition 9.5: Prefetch

The automatic delivery of image datasets from the archive to designated workstations based on predefined rules (e.g., “prefetch all relevant prior chest CT exams to the chest reading room workstations”).

Key Concept 9.6: Autorouting and Prefetching

Autorouting and prefetching attempt to predict which client machines will have need of data, and then send those data to the machine before it is requested by the user. Autorouting refers to data coming from modalities; prefetching refers to data in the archive.
9.2.2 Technology Strategies for Image Distribution

- **Extension of radiology PACS**: enterprise as “extension” of radiology department.
  - Extend radiology PACS network and workstation infrastructure to specific, limited number of enterprise locations (ICU, OR, ED).
  - **Pros**
    - Can provide full fidelity datasets
    - Image delivery performance can be high
    - Security may be more straightforward
    - Almost any legacy PACS can be “extended” this way
    - May be a viable approach for the small enterprise where there are just a few “image-intensive” user locations
  - **Cons**
    - Cannot practically provide ubiquitous distribution to “every desktop” (enterprise users may require this)
    - Forces relatively severe “triage” limitation of serviced enterprise locations
    - Expensive and lacks scalability
    - Difficult to integrate into EMR

- **Thin (web) client**
  - Addresses problem of limited network bandwidth and modest client resources by distributing images using “thin client” browser-based software, frequently via web browser plug-in (ActiveX, Java, Flash). A few vendors also offer browser viewers that use DICOM WADO that use HTTP/HTTPS exclusively and do not require a plug-in. We are beginning to see native browser viewers (“plug-in free”) based on **AJAX**, although performance is still relatively lacking.
  - Very popular strategy.

**Key Concept 9.7: Thin Client**

A thin client uses few resources on the local machine, instead relying on computing power from centralized servers. Thick clients, in contrast, rely more on the local machine.

**Definition 9.8: AJAX**

Asynchronous JavaScript and XML. A group of popular web methods used to create interactive web browser-based applications.

**Definition 9.9: WADO**

Web Access to DICOM Persistent Objects. Defines a DICOM standard to access DICOM objects via the web.
Common web-based image delivery technologies

- "Lossy" image compression: reduces size of image data by applying relatively “less bits/element” in the subregion of the image dataspace that contains less “useful information.” Frequently uses discrete cosine transform (DCT) or wavelet-based transforms. For example, JPEG images use DCT-based lossy compression.
- “Just in time” or “streaming” approaches: delivers that portion or subset of image dataset just when (or just before) it is required at arbitrary fidelity, including full fidelity if desired. Does not require lossy compression. Can provide very high image delivery performance. Examples include dynamic transfer syntax (DTS) and JPEG2000.

**Definition 9.11:**
**Dynamic Transfer Syntax (DTS)**
An example of a “just in time” data delivery mechanism designed to efficiently use constrained network bandwidth without the use of quantization-based (lossy) image compression.

**Further Reading 9.12: DTS**

**Further Reading 9.13: Image Compression**
Pros
- Can be cost-effective solution
- Can leverage existing enterprise IT infrastructure
- Image delivery performance can be high
- Integration into EHR straightforward

Cons
- Literature suggests that for most medical images, 10:1 lossy compression is probably acceptable ("diagnostic") with respect to image quality (both DCT and wavelet). Very large datasets may require significantly greater than 10:1 compression in order to achieve high-performance image delivery; may result in unacceptable image quality for some users. Must explicitly disclose this tradeoff between compression ratio and image quality to enterprise users; some "image-intensive" users may require/demand full fidelity or less aggressive compression ratios.
- "Just in time" or streaming approaches frequently employ "proprietary" image transfer technologies. Make sure vendors that offer this approach fully support the import and export of DICOM objects and transfer syntaxes when DICOM devices/workstations that do not support these proprietary protocols are also used.

9.3 Infrastructure Considerations

Here are a few practical suggestions with respect to enterprise image distribution infrastructure:

9.3.1 Archive/Web Server

- Persistence model. Enterprise users frequently require not only current/recent images but also relevant prior exams. It is important to understand the enterprise user requirements with respect to availability of prior images. There are two common archive/web server architecture models:
  - PACS archive augmented by separate enterprise image web server
    - These separate enterprise image web servers typically have a limited persistence cache that stores a subset of the PACS archive image datasets for a limited time period (e.g., the web server will store images for 6 months, thus providing rapid enterprise access to current studies and priors that are less than 6 months old). It is very important that the persistence model supports the requirements of the enterprise users; the "penalty" of having to wait for an image study that is not on the
web server and therefore must be fetched from the PACS archive will be unacceptable for most enterprise users.

- This limited persistence cache model can be “augmented” by intelligent prefetch logic (e.g., based on the enterprise user’s clinic schedule, relevant prior exams can be prefetched to the web server prior to when the patient is seen by the user). However, this usually requires the PACS or web server (or other workflow engine) to capture and consume the appropriate external (usually nonRIS-created) HL7 scheduling/ADT events.

- PACS archive with native or built-in support for enterprise image web server functionality.

- This approach has the advantage of being able to deliver via the web client all images that reside within the PACS archive. No prefetch or persistence logic is required.

- The enterprise user can be given a complete, comprehensive view of the patient’s medical image history.

- With some vendors, the enterprise user also shares a common view with respect to annotations, presentation states, etc. (e.g., if a radiologist adds a tumor measurement from her PACS workstation, these measurements are immediately visible to all users viewing the case throughout the system. Similarly, any annotations added by the enterprise user are accessible to the radiologist – useful for virtual collaboration.)

**Reliability, Availability, and Scalability**

- The enterprise image distribution infrastructure must be considered just as mission critical as the rest of the PACS, especially for “image-intensive” enterprise users and locations (emergency department, operating room, specialty clinics, etc.).

- Reliability and availability (percentage of time a system can be used with acceptable performance): for most institutions, must be 24/7/365. Appropriate redundancy and disaster recovery design and implementation are critical.

- Scalability (capacity of a system to provide acceptable service with demand expansion and growth): plan and budget for growth in demand.

### 9.3.2 Network

**Security.** Enterprise users will frequently use the image web viewer from outside the enterprise firewall. Common approaches incorporate VPN strategies;
HTTPS can be used if supported by web client. It is important to coordinate and leverage institution IT network security mechanisms and policies.

- **Wireless.** Increasingly in demand by mobile enterprise users. Vendor web-client offerings vary considerably with respect to performance using the shared nature of wireless network infrastructure.

### 9.3.3 Client Hardware and Software

- Survey existing enterprise client computers. Vendor image web-client offerings vary considerably with respect to CPU, memory, and graphics hardware requirements. Enterprise client computers are usually the last to be replaced in the health enterprise; be prepared to upgrade components as necessary.
- **Virtual desktop** (Citrix, etc.) approaches are prevalent. Be careful when running web-viewer software within virtual environment: performance and image quality may not be acceptable, especially to “intensive image” users.
- Must coordinate with enterprise IT to define roles and responsibilities with respect to training and support, including service-level agreements (SLA), helpdesk model, specifics with respect to how upgrades are “pushed” to all enterprise desktops, etc. When the system is down at 2:00 in the morning, the ED folks need to know whom to call.
- Must test and validate web-image viewer integration with EMR. As stated before, the majority of vendors offer some context sharing integration approach, such as vendor application programming interface (API), web service, or clinical context object workgroup (CCOW).
- For those enterprise clients who have diagnostic monitors, must develop and implement **routine scheduled monitor calibration procedures.** Consider use of automated, network aware monitor calibration, and reporting tools.

### Our Experience 9.15: Citrix Desktop

For Citrix users, consider using content redirection to have the Citrix virtual desktop instantiate the web viewer locally: while this may add to management complexity, performance and image quality can be significantly improved, especially for “image-intensive” users.

### 9.4 Specific Workflow Considerations

#### 9.4.1 ED/Trauma

- “Image-intensive” user.
- Will usually require diagnostic-quality images.
- Will usually require near real-time image delivery.
Frequently requires dedicated client with diagnostic-quality monitors.

Normal validation of images frequently not possible in trauma setting ("John Doe problem"); must provide efficient mechanism to deliver these images without exception creation, which can result in unacceptable delay and other inefficiencies.

**9.4.2 Operating Room**

- Two prevalent use models:
  - Pre-procedural planning (e.g., general surgery): images are viewed prior to performing the operation. Providing a web-based client within the operating room usually adequate.
  - Intraoperative image correlation (e.g., neurosurgery): images need to be viewed while performing the operation. Significantly more challenging. Frequently requires sterile mechanism for surgeon to manipulate image viewing software as well as display monitor easily viewable from operating table.

- Frequently will require diagnostic-quality images.
- Frequently will require ability to display multiple images and series; multiple monitor configurations may be required.
- Usually requires near real-time image delivery, including newly acquired intraoperative images.

**9.4.3 Specialty Clinics**

- **Orthopedics**
  - Usually will require diagnostic-quality images.
  - Usually will require near real-time delivery of images, including relevant priors. Frequently, relevant priors for orthopedics are not only the most recent images, but also the initial presentation image (which may be several months or even years old). Those using enterprise image web servers with limited persistence take note.
  - Usually requires access to images in every clinic room; images are frequently shown to patients for educational purposes, etc.
  - Specialized functionality such as prosthesis template planning frequently required.

- **Neurosurgery/neurology**
  - Usually will require diagnostic-quality images.
  - Usually will require near real-time delivery of images, including relevant priors.
  - Usually will require ability to efficiently display and manipulate complex, multispectral, multimodality image datasets (MR/CT).
9.4.4 Teleradiology (Primary Interpretation)

- Will require diagnostic-quality images.
- Will require near real-time delivery of images, including relevant priors. May require intelligent prefetching to the client.
- Will require diagnostic-quality monitors. Routine calibration is required.
- Will require ability to use dictation system remotely.

9.4.5 Advanced Visualization

- The significant increase in near isotropic volumetric image data has rapidly increased the adoption of advanced visualization software within the radiology reading room. Once limited to expensive dedicated stand-alone 3D workstations, the ability to manipulate these volumetric datasets using web-based thin clients (with and without plug-ins) has improved dramatically.
- Enterprise users (especially certain “image-intensive” users) are beginning to request/demand the ability to manipulate these image datasets using advanced visualization tools using thin client web-based technologies.
- Providing this service throughout the enterprise is challenging. The most promising approach involves the use of an “advanced visualization server–thin client” model:
  - Advanced visualization/3D image processing engine server with immediate access to complete isotropic image dataset from the PACS archive (or modality). Volumetric image dataset rendering and computation performed by this server.
  - Server communicates to web-based thin client via efficient “just in time” or streaming mechanism. Server only sends “results” of server-side computation to the client; the “heavy lifting is done by the server.”
  - Can allow for very high performance on thin web clients.
  - Much lower network and client resource requirements.

9.4.6 CD/DVD Import/Export

- This is perhaps the most disliked service we must provide. Many of us have gotten rid of our file room only to be overwhelmed by requests.
to import and images from CD or DVD. Unfortunately, for many of us, this process is still very inefficient and time consuming.

- Vendor offerings are still lacking in functionality; however, here are a few suggestions:
  - At the very least, vendors should create CD/DVDs with DICOM part 10 image files (preferably with a DICOMDIR directory of DICOM image files) in addition to the usual proprietary image formats and integrated viewer. You will have very little chance of success attempting to import a CD/DVD with proprietary images into your PACS.
  - Ideally, vendors should support the **IHE Integration Profile for Portable Data for Imaging (PDI)**. This will greatly simplify the import and export of image data using portable media (CD/DVD). Your vendor should support both the import and export of PDI compliant media.
  - RIS and PACS vendors should also support the **IHE Integration Profile for Import Reconciliation Workflow (IRWF)**. Although this process still requires some manual labor (most implementations still require you to schedule an “outside study” to create an accession number using your RIS prior to CD/DVD import), IRWF promises to greatly improve this inefficient and painful process.
  - Unfortunately, we are “stuck” with this unpleasant task until we get rid of CD/DVDs altogether and allow for **direct electronic distribution** of images.

**Key Concept 9.17:**
**IHE Integration Profile for Portable Data for Imaging (PDI)**

Guarantees that any image CD/DVD will have a DICOMDIR and DICOM part 10 image files (in addition to any “proprietary stuff”).

**Key Concept 9.18:**
**IHE Integration Profile for Import Reconciliation Workflow (IRWF)**

Provides the ability to efficiently reconcile imported image datasets by matching external identifiers with local identifiers (e.g., medical record number, accession number, etc.) so that the import of these “foreign” images does not cause inefficient exceptions that must be corrected manually.

**Further Reading 9.19: Integration Profiles**

from one enterprise to another using the Internet. While there are IHE workflow models for this, including Cross-Enterprise Document Sharing for Imaging (XDS-I) and the even more promising Cross-Enterprise Document Sharing-b (XDS.b), there are very significant technical, political, and economic challenges before we see this become “real.”

**Further Reading 9.20: Direct Electronic Distribution**


**Our Experience 9.21: Incorporating Outside Studies**

One last piece of advice: do not throw away your film digitizer just yet; many of us are still getting film that our enterprise users need digitized and stored into the PACS.

**Pearls 9.22**

- “One size does not fit all” with respect to enterprise image distribution; one must provide for the needs of a wide variety of users, including those who require full-fidelity/diagnostic images.
- Get early and constant input from all types of enterprise image consumers when designing and implementing an enterprise image distribution strategy.
- Many enterprise users will require near real-time delivery of image, including relevant priors. This will require thoughtful design of your enterprise distribution solution (web service persistence model, on demand archive, efficient network transmission protocols, etc.).
- Carefully consider the security requirements when enterprise users access images outside the firewall. Coordination with enterprise IT (VPN provisioning, Citrix access, etc.) is essential.
- For Citrix users, consider using content redirection to have the Citrix virtual desktop instantiate the web viewer locally: while this may add
to management complexity, performance and image quality may be significantly improved, especially for “image-intensive” users.

- Must test and validate web-image viewer integration with EMR. As stated before, the majority of vendors offer some context sharing integration approach, such as vendor application programming interface (API), web service, or clinical context object workgroup (CCOW).
- For those enterprise clients who have diagnostic monitors, must develop and implement routine scheduled monitor calibration procedures. Consider use of automated, network aware monitor calibration and reporting tools.
- The enterprise imaging distribution system is a “24/7/365” mission critical service. One must coordinate with enterprise IT to define roles and responsibilities with respect to training and support, including service-level agreements (SLA), helpdesk model, specifics with respect to how upgrades are “pushed” to all enterprise desktops, etc.

Self-Assessment Questions

1. Which of the following is a component of an enterprise image distribution infrastructure?
   a. VPN
   b. On-demand archive
   c. Diagnostic display monitors
   d. All of the above
   e. None of the above

2. Discuss the fundamental functional requirements of enterprise image distribution.

3. Which is NOT a common component of enterprise image distribution?
   a. On-demand archive
   b. EHR integration
   c. Auto-routing
   d. Web server
   e. Citrix

4. Which of the following can be used to deliver images to the enterprise?
   a. WADO
   b. Image compression
   c. Just in time data delivery
   d. All of the above
   e. None of the above
5. Describe the characteristics of an “image-intensive user”

6. Which of the following are examples of “image-intensive users?”
   a. Pulmonologist
   b. Neurologists
   c. Hospitalists
   d. All of the above
   e. None of the above

7. Describe the advantages of a PACS archive with “native” support for enterprise image distribution.

8. Describe how the IHE Integration Profile for Portable Data for Imaging (PDI) and the IHE Integration Profile for Import Reconciliation Workflow (IRWF) will help with your enterprise image distribution service.
Chapter 10
Reporting and Dictation

David L. Weiss and Peter R. Bolos

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10.1 Introduction

Since the discovery of the X-ray in 1896 radiology reporting has changed very little until the past decade. Very early reports were typed or handwritten by the radiologist. Later, reports were dictated into a recording device and later transcribed to text. Most reports were in prose format. Fewer were in a list or itemized configuration. There has been recent renewed interest in other reporting techniques. Speech recognition has been available for a number of years and has become more prevalent, albeit controversial, in the past decade. Although structured reporting has been available for a number of years, it is not widespread in radiology practice.

10.2 Newer Reporting Methods

10.2.1 Speech Recognition

Replacing a medical transcriptionist with a speech recognition (SR) software program has definite advantages in transcription costs and in speed of report turnaround. Unfortunately, many implementations result in decreased
radiologist efficiency. Choosing the right vendor and appropriate user training can help to avoid these drawbacks.

10.2.1.1 Vendor Evaluation

- **Product demonstration**
  - It is difficult to distinguish speech engine accuracy during a single session.
  - Evaluate the speech engine, but do not neglect other functions such as navigation and workflow.
- **Image viewing and reporting** are often performed simultaneously by the radiologist. Observe how these two tasks are accommodated by software and workflow.
- **Integration** with the PACS is highly valuable. An integrated system can improve radiologist efficiency and facilitate paperless workflow.

**Definition 10.1: Speech Recognition**
A software application that automatically converts spoken words into text. SR can replace a medical transcriptionist.

**Definition 10.2: Turnaround Time**
The time interval between the completion of a study and the study’s signed and finalized report becoming available in the medical record.

**Key Concept 10.3: Speech Recognition Engine**
SR software is conceptually divided into an “engine” that performs the actual conversion from speech to text, and an “interface” that provides workflow and interacts with other software applications.

**Key Concept 10.4: Implementing SR**
User buy-in and a project champion (preferably a radiology department leader) should be secured before any decision to implement speech recognition.

**Key Concept 10.5: Addenda**
Once a radiology report has been finalized by the radiologist, it cannot be modified because it is a permanent part of the medical record. Changes and clarifications must be added to the end of the report without changing the original report. SR software must support this workflow.
Step-by-Step 10.6: Vendor Evaluation

1. Assess speech engine accuracy, keeping in mind the limitations of short-term evaluation.
2. Observe multiple levels of users (residents, staff, experienced as well as struggling users) at a site visit.
3. Evaluate level of integration with PACS and RIS specifically as it pertains to your own software.
4. Assess radiologist workflow specifically pertaining to navigation of text while eyes are on PACS images.
5. Ensure both initial and ongoing application support. Will you or the vendor be training new users and supporting current ones?
7. Observe how dual reads, resident workflow, and addenda are handled.

10.2.1.2 Training and Applications – Initial and Ongoing

- Each user will require help with enrollment and instruction for several hours. It is best to divide this into at least two sections separated by at least several days of use. Some users will require multiple and ongoing remedial sessions.
- Initial applications are typically performed by the vendor. Before purchase, determine when and how often vendor will return to train new users.
- Consider, depending on site size, assigning at least one dedicated IT support person to speech recognition and have them trained by the vendor.

10.2.1.3 Speech Recognition Models

- The self-edit mode will achieve better turnaround time improvements and cost savings.

Checklist 10.7: Training Issues to Consider

- Expect a longer learning curve for part-timers and those radiologists moving from site to site with different reporting systems.
- If you plan to employ locum tenens you must accommodate this workflow.
- The software can accommodate many, but not all, heavy accents. If you have nonnative English speakers, plan for transcriptionist correction or alternative dictation.

- The transcriptionist mode is more acceptable to those radiologists who struggle with accuracy and a new reporting model.

Definition 10.8: Self-Edit Mode

Users dictate, edit, and sign reports without the aid of backend human transcription. Reports can be completed one at a time or batched.
Many sites successfully use a **hybrid model** allowing radiologists to choose whether to self-edit for any given report.

**Definition 10.9: Transcriptionist Mode**

Users dictate in a conventional manner, and SR is applied. The text and wav file are then sent to a transcriptionist where corrections are made. A corrected draft report is returned to radiologist for final approval.

**Key Concept 10.10: Batch Mode**

A radiologist may sign each report as it is dictated, or may dictate several reports and then sign them all in a batch.

**Our Experience 10.11: Pearls from an SR Administrator**

- Try to be involved in speech recognition as soon as you are assigned. It is not too early to sit in on vendor evaluation discussions.
- Shadow the vendor applications’ specialists and learn as much as you can about the software and its use during installation and training.
- Attend user-group meetings and make contact with other administrators.
- Be as visible as possible at all times within your department. If possible, make regular “rounds” and actively ask users if there are problems or issues that need attention.
- Try to sit as much as you can with the best radiologist users to learn tips on use and efficiency.
- Learn all you can about macros and templates. They are the key to user efficiency.

*Source: Gretchen Oman, RT, Imaging Informatics IT specialist in charge of speech recognition*

**Definition 10.12: Macros and Templates**

Predefined reports, words, phrases, or other data that are used to shorten reporting time. These can consist of an entire report and often are created with blanks that can be filled in with other data such as numerical values. Some distinguish between a macro, a complete stored report versus a template, a report created with blank fields for the easy insertion of other data elements, numerical, or otherwise.
Our Experience 10.13: User Acceptance

In a small community hospital of 100 beds performing 100,000 exams per year, the full staff of four radiologists agreed to implement speech recognition. Within one week, all radiologists were using speech recognition and no reports were sent to transcriptionists. Within four weeks, workflow and productivity were subjectively back to baseline levels.

In a larger more diverse department, the decision was made to implement speech recognition. Radiologists were encouraged but not required to use speech recognition. After six months, approximately 50% of radiologists had adapted speech recognition voluntarily. The remainder continued to use conventional dictation.

Key Lessons Learned

- Get as much initial buy-in as possible.
- Consider mandating use of speech recognition.
- Allow back-end transcription but incentivize use of self editing.
- Every term paper has a due date. Set an end point for removing manual dictation.
- In a large and diverse department, consider implementing in stages.

10.2.1.4 Problem Solving

- Radiologists may complain that speech recognition slows them down and distracts from image interpretation. These are the main reasons for resistance to SR. You might consider incentivizing the use of SR. This can take the form of tying incentive pay or extra days off to use of the software.
- Proper microphone position is \( \frac{1}{2} \)" from the corner of the mouth. We strongly recommend the use of headset microphones. These will maintain the proper microphone position even when the head is moved during image viewing.
- If the microphone is left on record mode while not speaking (often the case with radiologists used to conventional dictation), the system will have more errors and may freeze as it tries to convert background gibberish into text.
- Timing errors
  - Use of speech recognition is as much a cerebellar as a cerebral function.
– There is often a split-second delay after a navigation command while the system responds. Users must be aware of this and time their dictation accordingly; otherwise the system can freeze and/or create confusing errors.
– Likewise, there is a split-second delay when the microphone is turned on before the system is ready to accept spoken dictation. Users who are used to speaking simultaneously with pushing the record button will find the first syllable of their opening word truncated, which may lead to confusing accuracy errors.

Step-by-Step 10.15: Troubleshooting Poor Accuracy

1. The first task when called to a problem workstation is to check that the microphone is connected properly.
2. Next, test microphone and soundcard quality using the speech engine software. If this is unsatisfactory, change the microphone. If this does not work, the soundcard may be faulty.
3. Make sure that extraneous sounds are not interfering with accuracy. The worst of these are sudden loud noises such as doors closing or an overhead intercom.
4. Carpeting, acoustic ceiling tile, and sometimes acoustic wall panels are helpful. Consider the use of a white noise generator for problem areas.

• Speech files on the server not infrequently become corrupted files. With the vendor’s help, develop a strategy for dealing with this issue. It usually requires technical assistance that the end user may lack.
• Some words, even for the best users, will be problematic words. Try to add and train a word or phrase with the vocabulary editor if this is available in your system. Sometimes using an alternative word is possible (gouty arthritis versus gout).
• Users with heavy accents will require more training and more use of the vocabulary editor. As long as a pronunciation is consistent, the system can usually be trained given time and patience.
• Encourage users who are having recognition difficulty to use macros heavily. Unfortunately these are the users that often are hesitant to make full use of this feature.

Key Concept 10.16: Language Models

As it is used, the SR software learns the speech pattern, vocabulary, and accent of each individual user. This is called a personal language model. A radiologist who tries to dictate under someone else’s login will be unpleasantly surprised by the result! The language model can sometimes be modified manually using a vocabulary editor.
• Make sure that users understand to use the **vocabulary editor** or correction command when making corrections. The software is not trained by a typed correction, and thus, accuracy will not improve.
• Some users try again and again unsuccessfully to correct a single word. Encourage users to **correct phrases** rather than individual words.

### Hypothetical Scenario 10.17

A user tries to make a correction and insert the word “and” for the mistaken text “an.” These are near-homophones and the speech engine will likely not sense the slight difference in pronunciation. It is better to correct the phrase around the offending word to give more data and context. This will improve accuracy in dictation and especially in correction.

### 10.2.1.5 Navigation

• Remember that the user must navigate PACS and the speech recognition systems simultaneously.
• A good navigation system will allow the user to control speech recognition and PACS with a combination of voice commands and buttons without removing his or her eyes from the images.
• Different users will prefer different combinations of navigation.
• The microphone that comes with many speech recognition systems can be programmed by the user to control both SR and PACS. When using a headset microphone, these navigation controls can and should be preserved.

### Definition 10.18: Structured Reporting

There is some confusion as to the exact definition of structured reporting. According to Dr. Curt Langlotz, it can be considered in a three-pronged approach with three different features.

• Feature 1. A report that is consistent throughout with headings such as HISTORY, FINDING, and IMPRESSION.
• Feature 2. A report that lists organ systems in an organized itemized fashion with prose or shorter descriptive terms following each heading. This type of report is sometimes called an **itemized report**.
• Feature 3. A report that uses a standard lexicon with all findings codified within the database for billing, indexed search, and data mining capability.
• Consider the use of interface devices other than the mouse and keyboard. The exact type and configuration will depend on your PACS software and your interface.

10.2.2 Structured Reporting

• Most radiologists use a defined format with headings (feature 1 of structured reporting) within a consistently organized report.

• Itemized reporting (feature 2 of structured reporting).
  – These are preferred by clinicians; however, one study showed no time advantage for creation or interpretation versus conventional prose reports.
  – Itemized reports can be created using conventional dictation, speech recognition, or point-and-click structured reporting.

• Full-blown structured reporting, feature 3 of structured reporting uses a standard lexicon with all data elements tracked.
  – This type of structured reporting has created controversy among radiologists.
  – It is currently used most often in mammography reporting.
  – Some advanced visualization workstation vendors are offering this feature in their product.
  – Few radiologists have adopted this for general use despite its obvious advantages for data retrieval.
  – Most structured reports are created by a point-and-click interaction with a computer screen. This can be performed by using screen icons and/or a hierarchal menu.
  – Structured reporting systems should ideally be highly configurable with any pulldown menus customized by modality, body part, pathology, and user preferences.

10.2.2.1 Training and Learning Curve

• Structured reporting requires applications and training similar to speech recognition.
• There is a learning curve as radiologists become more familiar with software and learn shortcuts and workarounds.
• Of course, there will not be a recognition accuracy issue as with speech recognition.
10.2.3 Macros and Templates

Macros and templates are valuable in both speech recognition and structured reporting. Their use will determine in large part whether a user is efficient and accepting of the product. For speech recognition, the worse the recognition accuracy, the more important macros and templates become.

A systematic naming system across all modalities will be helpful to the user as more macros are added. Many users ultimately have over 100 macros.

Macros and templates should be created to be easily modified using only voice commands (for speech recognition). This will allow the user to remain focused on the images while creating a report.

With newer systems, the appropriate macro can be automatically selected and presented to the user by using data from RIS and modality, such as type of study and patient demographics.

Key Concepts 10.19: Macros and Templates

Macros and templates are a key feature of both speech recognition and structured reporting. Their use will determine in large part whether a user is efficient and accepting of the product. For speech recognition, the worse the recognition accuracy, the more important macros and templates become.

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Our Experience 10.20: Example of Easily Modified Macro

CT SCAN ABDOMEN AND PELVIS WITH IV AND ORAL CONTRAST
HISTORY: []
COMPARISON: [None]
TECHNIQUE: CT scan abdomen and pelvis. IV and oral contrast administered. Axial, coronal, and sagittal reconstructed images displayed at 5 mm.
ABDOMEN: liver is normal in size and CT density. Spleen is normal in size and CT density. Pancreas is normal in size and CT density.
Kidneys are normal in size. There is no hydronephrosis. No renal mass is identified. Adrenal glands are unremarkable.
Aorta is normal in caliber. No significant retroperitoneal adenopathy is seen. No ascites is seen.
Bowel loops are unremarkable.
PELVIS: bladder is unremarkable. Visualized pelvic organs are unremarkable. No pelvic mass or adenopathy is seen.
IMPRESSION: [no significant abnormality in CT scan abdomen and pelvis.]

Note that the brackets define fields that can be easily identified and modified.

Each organ system or related concept is a separate sentence. These sentences can be easily selected and modified using voice commands in either speech recognition or structured reporting. This keeps the eyes of the user on the images.

Any frequently used modification such as a one sentence description of fatty liver can be made into its own macro and inserted within this template.

Anything that a user is reporting more than once or twice a day should be made into a macro. This can be a full report or a part of a report.

10.2.4 Interoperability – Interfaces and Integration

- Interoperability of a reporting system, either speech recognition or structured reporting with RIS and PACS is essential. A standalone system is usable but virtually worthless in terms of department workflow and end-user efficiency. The quality of your interface and integration will have a major impact on radiologist acceptance and use of reporting software.
Hypothetical Scenario 10.21: Off-the-Shelf Software

Dude, I can save some serious coin by purchasing an off-the-shelf speech engine and using this for dictation. What is wrong with this strategy?

For a single radiologist without a RIS or PACS this is a marginally acceptable solution to improve turnaround time and save money on transcription. The speech engine could be trained for radiology report structure and a medical vocabulary could be purchased or added manually. Newer speech engine software will even allow multiple users and has increasingly sophisticated macro capability. What you are paying the reporting vendor for is mainly interoperability and workflow enhancements.

10.2.4.1 RIS Interface

- This requires a two-way interface. Accession number for a particular study is passed from RIS to the reporting database awaiting query when reporting shell is opened by the radiologist. Report text is passed back to the RIS for archiving and distribution to PACS, EMR, and ordering provider.
- Finalizing (radiologist signing) of reports should be available in the reporting system, RIS, and oftentimes PACS. Wherever reports are signed, the text should be transmitted back to the RIS and distributed to other systems.
- Creation of addenda likewise should be available within each system with text transmitted back to the RIS for archive and distribution.
- Multiple user (resident or dual read) workflow should be accommodated by the interface.

10.2.4.2 PACS Integration

- Most PACS now use an API with either the vendor or on-site programmers creating the interface. In either case, be sure to include these costs in the project budget.
- Schedule a site visit to see your prospective reporting system integrated with your specific vendor’s PACS and RIS if possible.
- **Hardware requirements**
  - Be sure to meet or exceed all vendor hardware specifications in any integrated system.
  - Both PACS and speech recognition are processor and memory intensive.
  - Users must be able to navigate PACS and dictate simultaneously without performance degradation.
- **SR embedded in PACS**
  - Some PACS vendors are embedding speech recognition software within their product.
– Whatever the type of integration, the level and quality of interoperability must be evaluated specifically for your own department’s workflow.

- SR embedded in RIS
- RIS vendors are likewise beginning to offer an embedded speech engine within their product in addition to some currently available mammography structured reporting products.
- While this may seem like the ideal solution, RIS vendors need to offer the same workflow advantages as third-party systems for the product to be worthwhile.

10.3 Lexicons

- Purpose of a lexicon: provide a common vocabulary to standardized enhanced communication and potentially reduce healthcare-related communication errors.

**Definition 10.22: Lexicon**
A related set or collection of terms, labels, or entities.

10.3.1 Current Lexicons

Examples of current lexicons in medicine:

- SNOMED-RT (College of American Pathologists)
- Unified Medical Language System (UMLS, National Library of Medicine)
- LOINC (Logical Identifiers, Names and Codes, Regenstrief Foundation)

Problem for current medical lexicons for the specialty of radiology:

- Little focus on imaging-related terms.
- A 2002 study by Langlotz and Caldwell concluded that current medical lexicons are insufficient to represent the contents of radiology reports with no current lexicon achieving greater than 50% completeness for imaging terms. This study confirmed results from multiple other smaller studies.

Solution: Creation of a **Unified Imaging Lexicon**

Potential Benefits of a Unified Imaging Lexicon

- Ensures a *standardized radiological vocabulary*.
- Allows for structured reporting systems with *automated differential diagnosis* and management based on imaging findings.
- Provides **data collection and analysis** in imaging research with comparison/combination of disparate research databases.
- Maintains automatic indexing and search of **teaching files**.
- Allows rapid **automatic coding** of clinical examinations.

**Why not the ACR Indexing?**
- The number-based, human-oriented method falls short in the computer-oriented digital age because the small number of unique terms and short, fixed digit numbering scheme limits detail expansion and prevents correspondence to related anatomy and pathology.
- This results in suboptimal annotating, indexing, and retrieving capabilities.

### 10.3.2 RadLex

#### 10.3.2.1 The RadLex Project – RSNA’s Solution to the Problem
- Main purpose to provide a lexicon to
  - improve clinical communication and clinical imaging research.
  - allow uniform indexing and retrieval of radiology information resources.
- Composed of
  - 15 committees
  - 150+ expert participant
  - 30+ participating organizations

#### 10.3.2.2 Promising Features of RadLex
- Adopts existing concepts from widely accepted standards (SNOMED-CT) and fills in the gaps where radiology terms are absent.
- Provides mapping with related, existing terms in lexicons such as CPT, ACR Index, UMLS, allowing versatility and practical utility.
- Freely available courtesy of the RSNA.

#### 10.3.2.3 Hierarchy of RadLex
- Term
  - Two term types: preferred terms (nomenclature) and synonyms
- Attribute of term (ancillary information)
  - Definition
  - Mapping to related terms in other terminologies or lexicons
  - Provenance information
10.3.2.4 RadLex Format

- To simplify the task of collecting terms by radiology experts, the lexicon is acquired using text files and spreadsheets.
- However, there are several problems with these text file and spreadsheet formats.
  - As it grows, the large RadLex hierarchy becomes difficult to browse, manage, and modify.
  - The lexicon is cumbersome for curation (i.e., detecting omissions, duplications, and inconsistency).
- Limits deployment into diverse computer applications that are continuously updating. Such applications include
  - User-friendly display
  - Structured reporting
  - Teaching file coding
  - Research data indexing
- Solution to this problem is to create an ontology based on the acquired RadLex lexicon.

10.3.2.5 Ontologies

- Benefits of an ontology
  - Expressed in a frame language or logic-based language (i.e., OWL) which provides distinction between the classes, attributes, and relations
  - Not committed to a specific storage syntax
  - Versatile
    - can processed in the domain of computer applications
    - can be created and stored in human-readable form
- Functionality
  - Provides a shared mode useable by both humans and machines
  - Helps curators analyze a database to identify omissions and structural inconsistencies
  - Allow integration in computer applications
- Protégé, an ontology development platform, is the tool being used to build the RadLex ontology.

Definition 10.23: Ontology

A domain that formally defines a set of classes of terms ("entities"), attributes of those terms ("slots"), and relationships of the terms.

10.3.2.6 Role of RadLex in Structured Reporting

- Structured text report using RadLex controlled terminology will provide reports void of the existing uncertainty and ambiguity currently contained
in free-prose, free-text reporting, similar to what BI-RADS has done to breast imaging.

- In addition, these standard terminologies when combined with the clinical data from the electronic medical record can be utilized for **clinical outcomes analysis** and **clinical decision support** to improve patient care based on evidence-based medicine.

### Pearls 10.24

- Remember to evaluate workflow functionality and not just report creation for both speech recognition and structured reporting.
- Take steps to maximize user accuracy in speech recognition including microphone position and proper dictation techniques.
- Plan on at least temporary productivity decreases when implementing speech recognition or structured reporting.
- Consider structured reporting for limited use until newer software is more mature.
- Encourage the use of macros and templates in both speech recognition and structured reporting.
- Carefully plan integration and interface strategies specific to your PACS and RIS.
- Become familiar with the RadLex project as a facilitator of structured reporting.

### Suggested Reading


Self-Assessment Questions

1. All of the following pertain to the use of macros and templates in speech recognition except
   a. they are essential for efficient use
   b. users should be encouraged to create their own macros
   c. should be kept to few in number to avoid confusion
   d. are most effective for users with poor recognition

2. When troubleshooting a radiologist complaining of poor accuracy in speech recognition you should do everything except
   a. check the microphone connection with the soundcard
   b. encourage the radiologist to speak more slowly
   c. check soundcard quality using speech engine software
   d. encourage the radiologist to use a headset microphone

3. A point-and-click structured report with tracked data elements
   a. is used predominantly in general radiology
   b. can improve radiologist efficiency and decrease distraction during image interpretation
   c. is ideal for data mining
   d. is better accepted by radiologists than is speech recognition

4. All of the following are true concerning an itemized report except
   a. it is preferred by clinicians over a conventional report
   b. it saves time both in report creation and report interpretation
   c. it is not common in radiology reporting
   d. it is a form of structured reporting

5. Concerning interoperability of speech recognition and structured reporting with other software such as PACS and RIS
   a. it is not necessary in smaller hospitals and imaging centers
   b. it improves mainly clerical but not clinical workflow
   c. integration is now standardized across all PACS and reporting vendors
   d. it may require an upgrade to workstation hardware

6. RadLex
   a. is a lexicon created by a single individual
   b. content was not dependent on existing lexicons
   c. decreases ambiguity in reports
   d. is simple and easy to manage
Chapter 11
Customer Relations

Janice Honeyman-Buck

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Our Experience 11.1: Customer Service Analogy

I’d like to start this chapter with a personal anecdote; something that happened recently to me that has immediate relevance to this topic. I was on a trip to Kansas to visit my daughter and rented a car in Kansas City to drive to Manhattan, a distance of about 135 miles. Service at my usually very competent rental company was far less than stellar, but I reasoned that it was only because it was rainy and cold and people were perhaps having a bad day and I was on my way to see my family and it didn’t matter to me. On Sunday afternoon of my stay as my family and I were off for an outing, my son-in-law noticed a large sidewall bulge in one of the tires in my car. I called for assistance and was told I would have to take the car to an “approved dealer” carrying the brand tire that was on the car, purchase a tire, and then present an invoice for reimbursement. This was Sunday afternoon, and I was leaving very early Monday morning. There were no “approved dealers” open so I took the car to a large box store that was open, had a tire put on the car and paid for it. One more relevant fact; the bulge on the defective tire had...
been clearly marked in chalk by the rental company and a tag with instructions was attached to the rim of the wheel. I did not know what codes the rental company used, but I was fairly sure that the instructions were not to go ahead and rent the car to a customer. I was inconvenienced by something that should not have happened, so I was not happy about it and am a little ashamed to admit that I practiced several conversations I would have with the manager in the morning when I returned the car.

On Monday morning, when I returned the car, I asked for the manager and showed him the tire with the circled bulge, the tag on the rim, and my invoice and prepared for a fight. He immediately apologized. He said he was so sorry, it was their fault, the entire rental was on him, he walked me to the counter where he counted out cash to reimburse me for the tire and took personal care to be sure I was taken to my gate for my flight. His individual attention, apology, and immediate resolution of my problem completely diffused the situation.

Clearly in this situation, the customer, myself, had a legitimate complaint and the manager was excellent in handling potentially hostile situations. Unfortunately, not all customers have legitimate complaints and not all customers are always right, but with the right set of tools, customer relations can be easier on both the upset user and the expert who has been called upon to assist in resolving a problem.

### 11.1 Customer Groups and Their Concerns

As an imaging informatics professional, **who are the customers?** Certainly this is not, strictly speaking, a business. Since images produced by radiology are used throughout the healthcare enterprise and are a critical part of a patient’s healthcare, almost anyone working in the hospital associated with a patient can be a customer. In addition, since images are produced by imaging equipment, modality vendors can be considered customers. Finally, the patients themselves are customers of the radiology services.

#### 11.1.1 Radiologists

Radiologists need their tools to be functional and efficient **at all times**. Radiologists are expected to read more studies in a time when studies are getting larger. Multi-slice CT scanners and new MRI units can produce literally thousands of images and the combination of the increased number of studies and increased number of images per study makes a workload that is nearly impossible to manage. A correctly functioning radiologists’ workspace that includes the PACS workstation, dictation system, and RIS/HIS/decision support access is absolutely critical to the success of the interpretation process. The IIP’s job is to be sure this need is met.
Hypothetical Scenario 11.2: Radiologist

Dr. Jones calls at 7:30 am on Monday morning – the keyboard on her PACS workstation does not work. When she types, nothing happens and everyone needs their studies read and this needs to be fixed immediately and why can’t we keep these workstations operational, she doesn’t have time for this kind of problem. As the IIP, you know that the keyboard has probably become unplugged from the computer. It will take 20 minutes for you to get to Dr. Jones’ location and that is too long for her to wait. If you ask her if the keyboard is plugged in, she will be embarrassed and perhaps more angry, a situation you want to avoid. Instead, try this. “Dr. Jones. I’m so sorry, this is entirely my fault. It will take about 20 minutes for me to get there, but I think if you help, we can fix this for you right now. Sometimes dust gets into the keyboard connector. If you would please unplug it, blow on it gently and plug it back in, it will probably work and I’ll come down as soon as possible to make sure it won’t happen again. Did that work? It did? Great! I’ll be down shortly.”

The IIP diffused the situation by apologizing, using the phrase “this is my fault” and then finding a solution that did not embarrass or talk down to the radiologist. The IIP recognized the fact that she could not get to the workstation location in a time frame that would meet the needs of the radiologist and worked out a solution on the spot that resolved the situation.

Checklist 11.3: Radiologists’ Work Areas

- Meet with a small group of radiologists regularly (e.g., monthly) to get a “wish list” of things that could be better.
  - Make sure that you include both computer-savvy and computer-incompetent radiologists!
- Have your support team check the work areas and computers for dust and tight connections weekly.
- Monitor the computers in the work areas for correct operation.
  - Reboot the computers regularly.
- Be visible; sit in each reading area for an hour every week to see how things are going. By being there, the radiologists will see you are interested in their problems and will often tell you about issues before they become critical.

11.1.2 Clinicians

With digital imaging and easy distribution of images, many clinicians now want to see their patient’s images as soon as the study is completed. When and how they get these images is a matter of policy and technology at each institution,
but clinicians commonly will access their patients’ studies using a web application. Of course, as soon as a web application for users to view images is implemented, users will begin forgetting their passwords.

**Thought Problem 11.4: Password Security**

You, as an IIP, do a spot audit of the web-based image distribution system to see how it is working and you are disturbed to see that one particular physician appears to be logged on in the medicine clinic in several different examination rooms. Since it is difficult for a person to “clone” themselves to be in multiple places at the same time, you investigate, only to find that all the physicians have forgotten their usernames and passwords so they have decided to use one person’s login, to give it to the clerk in charge of the clinic and to have her login to all the examination rooms at the beginning of the clinic to save time and they are all sharing one login. They know this is a violation of the security rules, but patient care comes first so they don’t care. How would you deal with this?

Prior to implementing a web application, there must be a way to manage users and passwords, preferably using a single sign-on system at the institution, perhaps using active directory or a similar system. Forcing a group of people to remember many different passwords encourages people to write passwords on slips of paper, bottoms of keyboards, and other non-secure locations, and leads to frustration and outright anger. The best solution to a forgotten password is an automatic way for the user to receive a reminder in an email, if that is not possible, then a 24/7 help desk must be in place.

While clinicians may be excellent physicians, they are not always good with computers and may have problems accessing images for their patients. When this happens, they are forced to call for help. Since these problems are difficult to anticipate, the best defense is a good offense, in this case, an excellent, short, on-line tutorial to help the new user navigate the system. While vendor-prepared user guides are comprehensive and useful, many users just want to log on, find the patient, look at the images, and log off. An IIP may find it useful to create a simple “splash page” that is the first thing the web

**Thought Problem 11.5: Timeouts**

The head of surgery calls you to complain that your web-based application time outs and logs off in the middle of surgery and demands a no-time-out login for the operating rooms. You know that human nature being as it is, that if you do that, people will use that login in other locations and you will be left with computers that do not timeout after a reasonable amount of time, a clear security violation. On the other hand, security should not get in the way of patient care. How would you deal with this?
user sees prior to being forwarded to the actual application. A two-page quick start guide in the form of a PDF placed on this page can often help new or infrequent users successfully navigate the system. Since the web access will quickly become mission critical for the institution, it is likely there will be a backup or business continuity plan and the splash page is a good location for placing a downtime announcement along with alternatives for accessing patient image information.

Some web-based applications will allow a machine-based no-time-out option that will allow users to login using their standard usernames. This means that if the computer accessing the application is deemed to be in a critical and safe location, it can be set up to not time out after extended periods of nonuse. If this functionality is used, the personnel in these areas need to be trained to periodically logoff the application or the computer operating system can be set to restart or shutdown after extended periods of nonuse, essentially forcing a logoff of the imaging web application.

In many locations, radiology departments are in competition for their patients and the clinicians are the customers who determine where their patients go for studies. Community or clinician outreach efforts in the form of educational programs on the services offered by radiology are an excellent way to publicize image access to referring physicians and to get feedback and ideas about improving the quality of image communications.

Checklist 11.6: Clinician Outreach

- Visit your community medical association meetings as a guest speaker.
- Attend staff meetings for other practices or departments.
- Publish an occasional newsletter with information and tips for better viewing of images.

11.1.3 Technologists

Technologists are critical to the production of high-quality, correctly labeled, and accurately identified studies. In the days of analog-film radiology, if a technologist made an error on a study, it was easy to correct with a grease pencil. Now, in the digital age, the incorrect image could be in dozens of locations before the error is caught. It is important for the IIP to understand how technologists “see” the radiology operation. In general, the technologists deal with a patient, the set up of a study, sometimes simple, sometimes very complex, and the technology that acquires the study. Technologists do not usually have a picture in their minds of the networks and computer interfaces that are necessary to implement the entire integration of the healthcare enterprise and they may not grasp the implications of the advantages of the work that is going on behind the scenes. They are trying to deal with what is sometimes the
difficult task of imaging a patient. And mistakes happen. And those mistakes are occasionally difficult to recognize and correct.

In order for the radiology department to run smoothly, it is important for everyone to understand how technology works together and how information flows. This includes the technologists. If they are educated about how orders are turned into a modality worklist and how the modality informs the RIS that a procedure step has been performed, the technologists will have an instinctive understanding of what is happening behind the scenes so if an unusual occurrence takes place, they will be able to help troubleshoot the incident and contact the correct people to resolve a problem. Thus, education is the key to correct technologist interaction with informatics technology as well as to job satisfaction.

- Even with the best integration and the best workflow, the technology will occasionally fail. Scheduled and unscheduled downtimes will happen, a portable modality may become disconnected from the modality worklist, a network may fail. The technologists should be well prepared to recognize that this has happened and be able to fall back on well-documented downtime procedures that make the process of doing their jobs as easy as possible.
- The IIP should schedule regular in-service times with technologist to educate them about the systems and to listen to their concerns. The IIP should occasionally shadow technologists in various divisions (Emergency Department, Portables, CT, US, etc) to see what challenges they face with using the equipment. This may suggest solutions to problems that were previously unknown.

11.1.4 Hospital IT

The IIP will most likely have a close relationship to the hospital IT group. Information from systems managed by hospital IT is most likely coming into radiology in the form of HL7 messages about admissions, discharges, and transfers. Orders and scheduling requests may originate from a system managed by hospital IT. In return, images and reports are being sent from radiology to systems managed by hospital IT. So, just like the integration of the healthcare enterprise, the people who manage these systems need to speak the same language, agree to protocols, and communicate information effectively. Cooperation on the communication of service and access issues can be crucial and essential to the successful integration and operation of all systems needed for successful patient care.

- The IIP should be part of the IT planning teams for new HIS, Computer Physician Order Entry (CPOE), billing, coding, and other systems that send information to radiology or require input from radiology systems.
- Hospital IT should be part of the radiology planning for new PACS, RIS, dictation, decision support, and other radiology-centric systems that need input from hospital systems.
Thought Problems 11.7: Hospital Personnel

- Scenario 1: A nurse from the neurology clinic calls; all the patients are there, but the doctors can’t see any of the CTs for any patients. PACS is down!!! Or, you might explain, perhaps someone has set a filter so that all you can see are CRs or MRIs. Consider what over-the-phone solutions might make the CTs show up again.
- Scenario 2: A clerk from the floor wants to schedule a study and can’t log on. Her password (which she knows for sure) doesn’t work, the system is locking her out! You might want to check to see if her caps lock is on. Or the even more subtle issue of a sticky shift key that is occasionally stuck if people eat food near the keyboard.
- Scenario 3: That nurse from the neurology clinic calls again; the PACS is not working correctly. When she tries to type in the patient’s name to search for it while the doctor is seeing the patient, sometimes numbers appear in the patient’s name field. You ask what type of computer is being used. A notebook computer? Aha! The elusive NumLock problem that many people do not understand about notebook computers.

11.1.5 Hospital Personnel

Everyone in the healthcare enterprise who has responsibility for caring for the patient may have permission to have access to radiology images and reports. For example, the physical therapist may need to see the CR and report on the shoulder radiograph while treating a rotator cuff. A clerk on a patient floor may need to schedule a CT examination. A coder needs to get access to reports to generate accurate codes so everyone can get paid for their efforts. All these users have their own unique interfaces, needs, and levels of understanding of the way the systems interact. All these users can and will at some time need help from the IIP when the system does not work as expected. There is no way the IIP can anticipate all the ways people can misunderstand how things work. What the IIP does need to be able to do is to get the right information from a user starting from what may be a complaint that makes no sense. For example, when a clerk complains that the monitor does not work, they may be saying the computer does not work. The IIP has to be the translator between the words users use to describe their problem and reality. The IIP has to have a sense of humor, a sense of compassion, a real commitment to service, understanding of technical weaknesses in others, and respect for other people and their knowledge levels.
11.1.6 Vendors

Without vendors, there would be no images, so they are a necessary part of the big picture. But vendors’ interests may conflict with the IIPs. A vendor wants a sale and to continue to make sales in a department, while an IIP wants equipment that conforms to IHE protocols, produces the best quality images, and has a user interface that makes the technologists’ work easier.

The IIP should set the standard for the expectation of IHE compliance from the beginning and make sure vendors are aware of the expectation to avoid conflicts during a purchase or upgrade. In addition, the IIP needs to be aware of any changes a vendor’s field service engineer proposes to make to any equipment prior to the change. There is nothing worse that coming into work and finding out that your CTs have had a field service change during the night and they no longer receive DICOM modality worklist nor do they perform DICOM send; in fact, they do not “see” the network anymore. The IIP needs to have a close working relationship with all vendors and field service engineers. No service or upgrades should ever be performed without prior knowledge of the IIP. By strictly stating and enforcing this rule, there should be an excellent working relationship between both groups.

11.1.7 Patients

Patients are our most important customers. While the IIP, as a peripheral part of the healthcare team, rarely interacts with patients, there are times when patients may need to know more about imaging, imaging services, and their images. The IIP is bound by the HIPAA rules and cannot give out any health information, and needs to make any patient aware of this from the beginning, but the IIP can certainly guide the patient to the correct person to answer questions.

The IIP needs to be sensitive to the real problems that patients are experiencing. Most people simply do not understand the complexities of technology, disease, treatment, or hospitals and are only looking for help. They do not understand the privacy rules that have been created to protect themselves and their families and may become hostile when you cannot help them for a very legitimate reason.

11.2 Tools of the Trade

Not all issues will have instant solutions and in fact, much of the IIP's customer relation tasks will consist of keeping track of ongoing and recurring issues and creating documentation and educational materials. The IIP needs tools and most IIPs will agree the tools are the best thing about the job.
Thought Problems 11.8: Patients as Customers

Here are some common scenarios (these have all happened to me):

- Scenario 1: Mr. Smith calls to find out how to get one of those digital whole body CT scans he saw on the early morning TV show that morning and somehow the call was directed to you because your name was associated with digital CT scans.
- Scenario 2: Mrs. Jones calls because she wants all her brother’s X-rays put on a CD so she can take them to another hospital.
- Scenario 3: Mrs. Brown is in the waiting room. She has some CDs of her neighbor’s studies from another hospital and she can’t make them work in her computer at home so she came in to find someone here to help her. Her neighbor is not a patient at your hospital.
- Scenario 4: The webmaster forwards a message to you because she doesn’t know who else can answer this question. The person has a son with cancer and she heard that digital PACS can cure cancer and want to set up an appointment.

In Scenario 1, I suggested that Mr. Smith call his physician to ask about getting an order for a scan. In Scenario 2, I explained that while we could do that, her brother would have to request it unless she was on his list of people who could act on his behalf because we had privacy rules. I explained to Mrs. Brown that her neighbor’s studies were private and I was not allowed to see them because of privacy. I responded to the person in Scenario 4 that if her physician didn’t refer her to our hospital, that we had a physician “finder” service which could help her find the best doctor and gave her the phone number. I did not explain that digital PACS could not cure cancer because I did not want to further confuse her situation.

That’s how I handled each scenario, but everyone will have to come up with their own responses as these unusual situations occur. There’s really no right answer, just a sensitive, caring, thoughtful answer. The IIP should be sure that when she interacts with patients that she has compassion. The patient has a real problem and even if he can seem unreasonable and may sometimes be angry, it is his situation and not the IIP he is attacking.

11.2.1 Documentation and Education

A complete description of software available for writing documentation is beyond the scope of this chapter, but there are some good starting places for many of the things an IIP may want to provide.

If an IIP wants to provide documentation of the system, educational content about how to use the system and make it available for everyone to view, the obvious place to put this is on the Internet using a web tool. If a Wiki is used to
implement this, other users can contribute to the documentation and the content can be quickly and efficiently developed.

Once the web space is established for documentation and education, as new developments are introduced to the department, a blog is a great way to publicize new services. If comments are encouraged, the IIP may learn more about what users want. Computer-savvy users may wish to subscribe to the blog with an RSS feed.

Pictures are the best way to quickly communicate how to use a system, so the IIP will need to be able to quickly capture a picture of a user interface to let the user know which button to click or where to enter information. One of the best tools around is called Snagit. For a very low cost (and multiple licenses are available), the IIP can select a portion of a screen or interface to grab and then save it in the image format of choice to include in documentation, either a web page or a presentation. Snagit may be purchased from Techsmith.com.

If documentation of systems includes patient information, the information should be de-identified. An open-source DICOM toolkit, DVTk, is available online that can manage many DICOM tasks including editing DICOM data to create anonymous datasets for training and documentation purposes.

**Definition 11.9: Wiki**
A page or collection of web pages designed to enable any user to contribute or modify content.

**Definition 11.11: RSS Feed**
Really Simple Syndication allows users to automatically receive the latest updates of a blog or website without having to directly visit the site.

**Further Reading 11.10: Wikis**

**Definition 11.13: Open-Source**
The source code for open-source software is available to users, software can be freely given away or sold (free distribution), and redistribution of modifications is allowed.

**Further Reading 11.12: Blogs**
11.2.2 Ticket and Issue Tracking

As technology evolves and becomes more complex, tracking and following up on outstanding issues is unmanageable without a well-thought-out system. This system should not be a color-coded set of post-it notes on a wall. Luckily, the IIP has excellent resources available to help solve the problem of keeping track of hundreds of tiny details. Sourceforge.net is the world’s largest open-source software development web site. There are literally thousands of open-source applications, most of them free, available to download and use. Of course, some are better than others and the fact that some are listed here does not mean they will work better, they are only suggestions. If the IIP uses an environment with the open-source relational database MySQL (http://www.mysql.com) and scripting language PHP (http://www.php.net), then PHP ticket may work to manage tickets. The MySQL and PHP environment are commonly used and are completely open-source but do require system administration knowledge to implement. Another similar program is PHPnuke. Both PHP ticket and PHPnuke are web administration tools for ticket management.

An open-source project management/communication/issue tracking/project Wiki tool that works very well is called Redmine (http://www.redmine.org). This web application is a cross-platform and cross-database tool that has been widely adopted and is well maintained. With its growing base of users, new features are added frequently and as usual with a popular open-source tool, programmers are constantly adding new plug-ins. The documentation is less than perfect and is a work in progress, but with the LDAP authentication, user self-registration, email notifications, file management, and other features, many users will find this a well-thought-out and useful system.

11.2.3 Proactive System Monitoring

Since the IIP would rather be contacted to hear about suggested improvements to a system or even praise about how well the system is operating instead of complaints about systems that are nonfunctional, a proactive monitoring approach can be used to identify errors before users

Further Reading 11.14: DVTk

Definition 11.15: Digital Dashboard
A graphical interface that summarizes input from many sources into a small visual area that can be quickly understood.
are aware there is a problem. These systems can provide the IIP with a **dashboard** that shows how things are working and identify if there is a weakness that needs to be addressed. In fact, the IIP does not have to be watching the computer; the **monitor software** can page, email, or call the IIP if a problem is detected.

An open-source availability system has been developed exactly for this application and is available for download. Researchers and developers the University of Maryland developed **Nagios** software to proactively monitor systems such as PACS and RIS, alerting IT support when failures are detected. Nagios can give the IIP instantaneous information about the state of all the systems in the network and records complete logs for periodic review. In addition to being able to proactively manage immediate problem events, periodic review allows the IIP to look for patterns of weakness in the network or in specific systems.

### 11.3 Last Thoughts

The IIP needs to be aware of the customer relations side of her job and be prepared to be helpful to those users who may not be a technically savvy or who may not understand how the systems fit together. Education can certainly help, compassion and understanding of the stresses of other people’s positions is important, and tact is always needed. Keep a notebook of the funny things people complain about; maybe someday you will write a book. Finally, look for tools to keep on top of the issues that will make users call with complaints and try to avoid problems before they happen. If the IIP makes herself available, visiting the areas where users are working on a frequent basis (this means daily), the users will know she is interested in their jobs and will be less likely to complain. This can be a five minutes trip through the ultrasound department to say hello to the technologists or five minutes in a reading room, but that is all it will take to make the job easier. One last word, make sure you know your users and their names; it will make all the difference in your job and your job satisfaction.

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**Further Reading 11.16: Nagios**


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**Further Reading 11.17**

Pearls 11.18

- Everyone is a customer.
- The radiologists’ workspace must work correctly at all times.
- Education is the key to correct technologist interaction with informatics technology as well as to job satisfaction.
- Education and communication are the keys to successful dissemination of images throughout the enterprise.
- The IIP needs to have a close working relationship with all vendors and field service engineers. No service or upgrades should ever be performed without prior knowledge of the IIP.
- The IIP has to have a sense of humor, a sense of compassion, a real commitment to service, understanding of technical weaknesses in others, and respect for other people and their knowledge levels.

Self-Assessment Questions

1. Who among the following is a potential customer for an imaging informatics professional?
   a. Patients
   b. Radiologists
   c. Vendors
   d. Hospital IT
   e. All of the above

2. If a patient has a question about how to access his or her images on the Internet, the imaging informatics professional must teach the patient how to access the images from home.
   a. True
   b. False

3. Which of the following systems that are used by the radiologists are typically supported by the IIP?
   a. PACS workstation, email, Internet
   b. HIS interface, PACS workstation, dictation system interface
   c. Dictation system, Internet, Microsoft office, email
   d. HIS/RIS, dictation system, turbo tax

4. Which of the following techniques might help keep the radiologists work areas run smoothly and correctly?
   a. Regulate exactly when each computer can be used and how it can be used so that no one can use it during a scheduled downtime and so you have complete control over its use.
b. Change the passwords on the reading room computers every morning at 6 AM with an automatic reboot to enforce security.
c. Monitor the computers in the work areas for correct operation.
d. Purge all the images and databases from the PACS computers every morning at 7AM to be sure they start fresh each day.

5. How can a Wiki be used to provide documentation of information systems?
   a. The IIP can download the information about each system from Wikipedia.
   b. The IIP can upload the documentation provided by vendors to Wikipedia and make it available to everyone.
   c. The Wiki installed on the institution’s intranet can be modified by qualified personnel to inform all information systems’ users about new features and proper use of the systems.
   d. The Wiki installed on the institution’s intranet can be modified by qualified personnel to download Wikipedia information.

6. What types of things can you expect to find on sourceforge.net?

7. What advantages can you expect from proactive system monitoring?

8. What features does Nagios software perform to help the IIP?

9. What solutions can you put in place to help users who forget their passwords?

10. What types of clinician outreach techniques might help improve communications with clinicians?
Chapter 12
User Training

Ann L. Scherzinger

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12.1 Introduction

Training is an ongoing requirement of a successful PACS program. Staff turnover, workflow changes, upgrades, new systems, and general performance improvement initiatives should all trigger some form of formal staff training if your organization desires accurate and consistent information and workflow from your informatics application. The following discussion defines four common aspects of all training programs. Generally, these are performed sequentially; however, continual assessment of the program should be performed and may require redesign of an earlier component.

Key Concept 12.1:
Purpose of Training
Training instruction has one primary goal: better job performance.

Further Reading 12.2: Training
Training instruction is normally a Human Resources function and literature related to training systems development can be found by searching topics such as Rapid Prototype Design, Instructional System Design, and Performance-Based Training.
12.2 Assessing the Need

- Assessing training needs typically involves determining the **why, who, what, where, when, and how** of a training program. The outcome of this process should be a preliminary training plan.

- **Why of training – determine the purpose of the training**
  - **New software and upgrades** are obvious reasons for a training program and typically a system implementation plan includes training phases.
  - **New staff members**, both within and outside the department, require access to a training program that allows them accurate and efficient use of appropriate information systems to do their job.
  - **Workflow changes** from new programs or quality initiatives often dictate training or re-training of staff. It is important for the PACS administrator to be involved in any new program analysis to assure that workflow changes can be supported by the PACS system.
  - **Performance review** of an individual staff member may dictate re-training.

- **Who and what to include in the training**
  - The outcome of this portion of the needs analysis should be a **list of users, their roles, and a description of tasks with appropriate performance measures that each user or user role needs to learn.**
  - For new systems and system upgrades, the best way to determine the training tasks and audience is through review of the workflow assessment that was done by the project implementation team. That workflow was most likely done to assess equipment needs and placement and may not have the details needed for training. To be useful for training, it should describe the normal flow of data as well as decision points when the normal data flow is modified. A workflow document should be created for all user roles. A **comparison of the new workflow with that of the existing** will best indicate who and what should be included in the training plan.
  - **Role-based workflow** analysis will best determine the training program for a new staff member. Review the role-based workflow with the staff member’s supervisor to assure that it is current.
  - The recommendations of a performance assessment or the description of a new program will include workflow changes. The PACS administrator will
Thought Problem 12.4: Adding a New Module
In adding a new Mammography module to the PACS, there are often CAD documents that need to be incorporated. What other users need to understand the type of reports that might be on the PACS from a CAD system?

need to review these to see if changes affect users and processes beyond the immediate scope of the proposed change to see if additional staff training is required.

- For re-training of an individual staff member, review with a supervisor the tasks that should be included. It may be beneficial to review system workflow beyond the user’s current focus to enable a better understanding of their role and its effect on downstream users.
- For each user, obtain a list of their roles, their normal work hours, and availability outside of normal hours.

- **Where to train**
  - The outcome of this portion of the needs analysis should be a list of training facilities available to your department as well as the process for reserving these facilities.
  - Determine the facilities that are available for teaching at your site.
    - **Computer training classrooms.** How many workstations (typically classes should be no larger than 8–12 users)? When do they need to be scheduled? Who will load your application or make it accessible? Is a projection system available?
    - Is there available equipment, unique to your system, (scanners, printers, bar code equipment) that can be relocated for training?
    - Is there an area that can be set up for follow-up training after the primary training occurs?
    - If one-on-one training is desired, is there a quiet location where this can occur without affecting normal workflow?
  - Can all users come to a central location for training or will you need to provide some training in off-site facilities?
  - Does your facility have the ability to support web-based training programs? Is there a Learning Management System (LMS) that can monitor training use and performance?

- **When to train**
  - How soon before “go-live” should training occur? Users need time to practice skills prior to use, but training too early will most like result in loss of skills prior to “go-live.” Group training often occurs just prior to the “go-live” simulation and users can practice during the simulation.

Definition 12.5: Learning Management System
System that supports the delivery, tracking, and management of training resources and user evaluation.
Small changes or additions to workflow may be taught with on-the-job training, just prior to first use.

Users receiving one-on-one training prefer to be trained just prior to go live.

Coordinate all training with area supervisors. There may be other circumstances, such as the arrival of new imaging equipment or other staff commitments, which affect staff availability for training.

If a vendor is involved in training, when are vendor trainers available?

Create a policy and procedure to make training available to new users as they are added to an existing system.

**Typical Training Methods**

**Train-the-trainers**

- In this scenario, vendor trainers train department superusers, who then train the remaining staff. Normally superusers become a valuable part of the support for all users in their area, even after go-live.

- Staff chosen for this role should be comfortable with information systems, upbeat and have a good rapport with the users they train. They will need to understand the workflow of the area and be able to communicate issues to the primary PACS support team.

- This method requires a large time commitment from department staff. The superusers need to be given time off from their normal duties for training and to get a comfort level with the new system. Superusers need to become experts so that they do not pass on faulty information. Additional cost occurs if a superuser leaves the organization during the training period.

- Train-the-trainers works well for outpatient clinics and referring physician offices. A lead technologist or clinic nurse can be an ideal superuser and is on site for PACS support.

**Vendor training of all staff**
• Typically, vendors include a set number of hours of training as part of the contract. If the new application is not a major change to workflow, the vendor could train the bulk of the users in the time that it takes to train superusers.
• This method decreases the time commitment of your staff but may be more expensive and less flexible and you will still need to provide training for staff who is away when the vendor training takes place.

  – IT staff as trainers
  • Some sites have IT staff that can serve as application trainers.
  • The vendor trains the staff pool in group sessions.
  • Such staff should have the skills to provide adequate to excellent training; however, they need to be pretrained in the workflow of the department and are not normally available for guidance after go-live.
  • Scheduling of IT staff normally must be done well in advance and may not be very flexible to modifications in the training schedule.

  – One-on-one training
  • Individual training sessions should be used for some users, particularly those who are difficult to schedule (physicians), need customization of an application (radiologist for hanging protocols and standardized dictations) or need more detailed technical information (support staff).
  • Training typically takes place at the users normal work area in one-hour sessions just prior to go-live.
  • Basic tasks are normally covered in the first session and plans should be made for follow-up sessions to learn advanced applications or further customize the users interface. Typically, this occurs after go-live and after the user has had one to two months to work with the system.

  – Electronic Media
  • An on-line training module can be very useful for training of hospital staff who have limited use of the system (review results in the clinic).

Further Reading 12.8: One Hospital’s Experience

Further Reading 12.9: Create Your Own
• Electronic media provide a standardized presentation that is accessible at the convenience of the user. If developed in-house, it can be tailored for your organization.
• Users can be sent a link to the module when their access to the system is activated. Some hospitals require a user to review the on-line training module before getting access to the system, but this requires a Learning Management System (LMS) to be really efficient.

12.3 Design and Development

• In creating workplace training programs, adult learning principles should be utilized.
  – Training should be relevant. Adult learners need to know why the lesson material is important. Clearly define how the new knowledge is relevant to their job performance. Change is particularly difficult if the reason is not understood. Remember that medical personnel are motivated by patient service goals. It may help to relate the new application to service and the hospital strategic plan.
  – Adult learners are generally autonomous and self-directed. They have formed a concept of how they best learn and what their learning needs are. They may be resentful if they feel others are imposing a learning structure on them. Although the material to be presented may be dictated by the software change, users should be involved in planning how the training experience is designed. Classroom situations should be flexible in order to respond to the variety of adult learning styles.
  – Teaching will need to take into account the learners foundation of prior experiences and existing knowledge. Adults have an acquired set of habits and biases that can affect learning and may make them resistant to change. This includes prior workflow processes, software terminology, and workplace experiences. Past experiences may facilitate learning if they can be connected to the current learning experience. However, they can be harmful if the training is attempting to effect a change.
  – Adults are receptive to learning information and tasks that they perceive will help them perform. Workflow and expectations are important. Be able to answer how each step in the workflow will help provide a better result for the patient or fewer system problems with the patient record. Timing is important, as training too soon prior to a change will be met with little enthusiasm.

Our Experience 12.10: Translation Table

When converting to a new PACS vendor, we found it useful to create a translation table for the training sessions. That way, the vendor trainer and the user trainee can see that “Exam Type” in one system is “Procedure Type” in the new system. This facilitated a transfer of skills from one system to the next.
- Adults are **problem or task-centered** learners. They are **goal oriented**. Clear learning objectives that are tied to specific tasks should be created and shared with learners to motivate their participation. The training environment should be as close as possible to the work environment. On the job, training is very effective but not always practical.
- Adult **learning motivation** is affected as well by a number of external and internal factors.
  - **External motivations:** to fulfill the expectations or recommendations of the job or an association (CME), to obtain a better job or to provide service to the community.
  - **Internal motivation:** to achieve higher job satisfaction, to improve self-esteem, to learn for the sake of learning.
  - Motivation is difficult to sustain; however, if other adult learning principles are not followed during training.
- **Create learning objectives** for each task defined for each staff role.
  - Creating course objectives **is a process by which abstract goals must be converted into measurable objectives.**
  - For workflow and software training, the goal is typically defined by a **hospital goal** (why did you buy the new system or change the workflow) and **mastering the tasks necessary to achieve the goal is the measured objective.**
  - The value of each objective is that both the **learner and the supervisor will know what competency (skill or ability) the learner will acquire from the training.**
  - Basic concepts and rules of creating measurable learning objectives include
    - A learning objective should define **what the learner will be able to do** following the training.
    - Typically objectives begin with the phrase “After attending this course the student will be able to...”
    - This is **followed by an action verb** chosen from those found in Bloom’s Taxonomy. Verbs range from those that describe the lower levels of learning such as knowledge of material, through mid-levels such as the application of learning to perform a task, to higher levels such as the synthesis of learning to formulate or evaluate new procedures.
    - The verb is then followed by the **specific task to be measured.**

**Further Reading 12.11:**
**Adult Learners**

**Further Reading 12.12:**
**Writing Objectives**
Select a delivery method

- **Adult learners** need to be accommodated with a variety of **training strategies**. Typically, three types of adult learners are identified.
  - The **visual learner** prefers documentation and presentations.
    - Provide **written instructions, illustrations, charts, and graphs** as appropriate.
    - Orient them to the user manual by describing the table of contents.
    - The visual learner is typically well organized and may study by outlining. Present outlines or “cheat sheets” on how to perform tasks.
    - Use a variety of visual examples of task performance and outcomes, including errors that can occur.
  - The **auditory learner** prefers verbal instructions and can remember what they are told.
    - **Verbal repetition and discussions** enable the auditory learner. Rephrase points and present questions in several different ways to stimulate discussion.
    - **Jokes and anecdotes** are appreciated and may stimulate memory.
    - Auditory learners find it **difficult to work quietly for long periods**.
    - **Incorporate multimedia** to vary the speech and aural texture of the presentation.
    - Ensure that the teaching location has adequate acoustics.
  - The **kinesthetic learner** remembers best by getting involved.
    - **Has good motor coordination**.
    - Provide many opportunities for **hands-on** use of the system.
    - A kinesthetic learner has **trouble staying still for a long time**. Often he/she will go ahead of the lesson plan and miss some of the workflow detail. Provide lots of scenarios to illustrate all facets of workflow.
    - Permit frequent breaks.
Thought Problem 12.15: Your Class Consists of Auditory and Kinesthetic Learners

When this occurs, try having teams of students prepare each scenario and present it to the class. Students are more likely to listen when their peers are presenting and you can incorporate questions, cautions, and pearls during the presentation.

- **Create or acquire training materials**
  - Ask the vendor for training materials. At a minimum, they should have materials for new applications. If the vendor is doing the training, review all materials to make sure they are consistent with your workflow and the expectations you have of each staff role. Obtain electronic copies of training materials and cheat sheets. These can then be modified for your facility(s).
  - Review the materials against the adult learning styles discussed above to assure that you have a variety of presentation styles.

- **Update workflow and procedure documentation**
  - As part of any process change, upgrade, or new install, workflow and procedural changes will naturally occur. **Documentation should be upgraded** as needed to incorporate these changes.
  - The training program should begin with a review of the new workflow and tasks should be related to the new workflow. Make copies of the workflow for each of the staff roles being trained.
  - The organization’s training manager should **review workflow with the vendor and trainers** prior to any staff training sessions. It is particularly important to review how the workflow will change. It would be ideal for the trainers to know the system that is being replaced as well – relating the new application to similar tasks performed on the old system facilitates the transition.

Key Concept 12.16: Cheat Sheets

Manuals typically are multipage and contain screenshots and lengthy text describing how to perform a task. Although useful for training, most users prefer to have single sheet with a brief list of steps and perhaps an icon representing the task button or field.

Our Experience 12.17: Aiding the Transition

Many users adapt quicker to a software application change if you can directly relate your new application to the one they currently use. Do this by creating workflow documents with screen shots of the old and new procedures.
As training occurs, it is likely that the workflow will be altered or enhanced. Modification of documentation and training sheets may be required and should be done prior to the next training session.

- Create testing materials that correlate with the learning objectives.
  - Review vendor testing materials. Typically, this testing consists of simulated scenarios that require the user to perform the appropriate steps in the application.
  - Do the materials cover all common scenarios? Are there scenarios that cover workflow variation such as
    - Points in the workflow that require a user to decide the appropriate action.
    - Steps required in order to recognize or correct errors.
  - Validate that training and testing materials are consistent with the course objectives.
    - Each objective should have corresponding teaching and testing materials.
    - Do the materials cover the breadth of information needed to do the jobs?

12.4 Implementation

- Create the training plan to include days, times, locations, and users being trained.
  - The plan should be finalized at least one month in advance and made available to all users being trained and to the trainers.
  - Scheduling should be done by user role so that users only receive training on areas that are within their job scope.
  - Work with administrators and supervisors to determine a training schedule that is consistent with department operations. If staff are trained during their normal shift, insist that department operations are reduced during the training period.
  - Third-party applications may require a separate training schedule and arrangements with the third-party vendor.
  - Follow-up, post go-live training may be required for advanced applications. Examples include, advanced hanging protocol set-up or third-party image processing applications.

Key Concept 12.18: Training Groups

If you know that some users are less comfortable with computer applications, group them together for training. If possible, keep the group size to 8 or extend the class period so that the group will have more time for practice and questions.
- **Preparation of the site learning environment**
  - The goal of any training is to enable an employee to utilize the skills learned in the classroom, on their job. Transfer of learning happens best when an employee has appropriate ability, motivation, and environment factors in place (Holton et al., 2000; Choi and Ruona, 2008).
  - **Ability to transfer** is enabled by
    - A match between the training content and environment and the tasks learned.
    - Availability of resources and decreased workload to enable study.
    - Physical workplace design to enable use of new skills.
    - Ability to immediately use the new skills on the job.
  - **Motivation to transfer** is affected by
    - Employees desire to improve skills.
    - Trainer’s style.
    - Expectations of the job.
  - **Environment to transfer** factors include
    - Organizational support and involvement from supervisors and peers.
    - Establishment of specific goals, regular and follow-up feedback from trainers and supervisors.
    - Defined match between department and organizational goals and the new learning material.
    - **Secondary influences** seen to affect motivation and training success include employee disposition, attitudes, and the organization’s learning culture.
    - Review issues with the department administrator and supervisors to eliminate any environmental factors that may impede staff from learning and performing their new duties.
  - Set up the **training system**
    - Set up your test system for training with all or a representative sample of all of the dictionaries on the live system. Many users will want to try scenarios beyond those planned for the training class. The more real

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**Further Reading 12.19**

- This document contains a useful matrix chart of learning participant roles: Transfer of Learning: A Guide for Strengthening the Performance of Health Care Workers. Available at: [http://www.reproline.jhu.edu/English/6read/6training/tol/index.htm](http://www.reproline.jhu.edu/English/6read/6training/tol/index.htm).

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**Key Concept 12.20: Employee Motivation**

An employee will consider training as important only if their supervisor does. A trainee should not have to worry about the work that is piling up while they are in training. Bring in extra staff or schedule down during training.
that you can make the training system, the more relevant the training will be.

- Set up users with the **roles and privileges that they will have in the live system**. They will not be confused by options and screens that they will not be using and will not see during the “live” environment.
- Have the trainers **create the patients and studies required for their training** scenarios. Scenarios should be as close to the job experience as possible. When training staff, make sure that there is time for the learners to construct their own scenarios and to make and correct errors.

  - **Create ongoing training and support materials**
    - Knowledge retention depends on frequent use of information. Seldom performed tasks benefit from **Electronic Performance Support Systems** (Gery, 1991). A study by Nguyen (2005) concluded that **end users preferred context sensitive, on-line, help systems**. In this survey users preferred to click on a help button to open a window providing information on how to perform a task. Users also desired the ability to bookmark or print these help pages.
    - Traditionally **cheat sheets should be laminated and placed near workstations** for routine, and perhaps more importantly, seldom performed tasks.

**Checklist 12.21: Cheat Sheets**

Cheat sheets should provide an abbreviated list of the steps required for a task. Additionally, they should list any keystroke shortcuts that have been defined on your system.

### 12.5 Evaluation

- Most educational assessment tasks involve both **formative** and **summative** assessments.
  - **Formative assessment monitors the learning progress throughout the learning cycle**. The intent is to give the rapid feedback as a means to motivate learning and to give the teacher the ability to adjust the teaching process if needed.
  - **Summative measures are performed at the end of a learning cycle**. Often they include an exam that measures what the student has learned and/or what the teacher has successfully taught. They can include on-the-job assessments as well.
  - Both processes are necessary ways to monitor training activities in the workplace. They are useful only if they provide an **accurate assessment** and are used to **enhance the training program**.
  - Both should be **performed and reviewed continually** during the training period.
• **Assessment measures should be developed along with the training plan** since they should be a measure of how well the goals of the training are achieved.

• **Authentic assessment practices** became popular in the 1990s as a means to assess whether the training received actually enhances job performance.

• A common scheme for authentic assessment of corporate training programs was developed by Donald Kirkpatrick (1998). The **Kirkpatrick 4 Levels** of evaluation included

  - **Level 1**: assessment of the students’ reaction to the training program. This is done by surveys that ask the users to evaluate the topics, materials, course design, and instructor. An inference is made that positive employee reactions to the training program motivates learning. This level of assessment is used to enhance training materials and course content but does not test whether any learning has occurred.

  - **Level 2**: self assessment by the users as to whether the program met their learning goals and skill testing of learners by the instructor during the training session. Such exams can assess skill level at the time of the instruction but do not necessarily indicate whether those skills are retained on the job. A study by Ford and Weissbein (1997) concluded that only 10–30% of such knowledge translated into on the job skills.

  - **Level 3**: on the job assessment of skills learned is typically done by a supervisor. Results may be affected by supervisor distraction or by the type of work environment at the time of the review. Modern applications using computer-based performance testing remove the bias of supervisor assessment for computer-based tasks (Galloway, 2005).

  - **Level 4**: assess business process improvements that result from enhanced user training. Typically, this includes such enhancements as improved quality, production, sales, customer satisfaction, or reduced costs. This type of evaluation is most beneficial when justifying on-going training program resources to managers. However, proper evaluation requires isolation of the contribution of training versus other process changes that may have contributed to the enhancement of outcomes.

**Definition 12.22:**
**Authentic Assessment**
Evaluation of learning based on real work tasks.

**Checklist 12.23: Skill Testing Metrics**

- Were the correct tasks performed?
- Were the tasks done in the right order?
- Was the proper result obtained?
- Was the task performed in a timely manner?
Return on investment (ROI) analysis can provide a financial assessment of a training program.

- ROI analysis is done to justify the cost of providing a training program by providing the management a monetary return on investment.
- Typical analyses build on the data collected using the Kirkpatrick model.
- Common metrics used include the benefit/cost ratio (BCR) or a traditional ROI. (For thought on the current status of ROI analysis, see Phillips and Phillips, 2008).

Pros
- Administration is able to see a tangible value to training.
- Helps to point out where training activities are most effective for the organizations profit.

Cons
- Isolating the effects of a specific training can be difficult.
- Calculating the benefits of the training can be very subjective.
- Analysis can be very time consuming, especially if the application involves many users or processes.

In healthcare, competency testing (Miller, 1990) is done at four levels of assessment that correspond closely to those of Fitzpatrick. Studies however involve technical skills, problem solving, and patient interactions that are beyond the scope of the standard PACS training environment.

Creating assessment materials. Important considerations in creating survey and testing materials include

Step-by-Step 12.24: ROI Analysis

1. Collect data from Kirkpatrick’s level 4.
2. Assess whether the application had a measurable result.
3. Isolate effects due to training.
4. Convert results to monetary benefits.
5. Determine the cost of training.
6. Compare the monetary benefits to the cost.

Further Reading 12.25: Further Measures and Details of an ROI Analysis


Key Concept 12.26: Stages: Professional Competency Assessment Levels

KNOWS (factual recall)
KNOWS HOW (describes procedure)
SHOWS HOW (performs in controlled setting)
DOES (performs in real setting)
- **Align exam/survey content with training course objectives.** Make sure that you are testing what you want the student to learn.
- **The time devoted to a concept should reflect its relative importance.**
  - The most common form of program evaluation is the *survey*. These can be effectively used for Levels 1, 2, and 4 of the Fitzpatrick Model.
- Survey implementation typically involves five steps:
  - **Establish the goal of the survey.** What do you want to know? For user satisfaction during training, this typically includes whether the training materials and presentation are clear and easy to follow, whether the learning environment is appropriate (proper lighting, visuals, and sound system) and whether the users feel the material is relevant to his or her job duties. For process improvement evaluation (Level 4), this may include patient or referral satisfaction surveys.
  - **Plan the survey design.**
    - What is the appropriate survey length and question format?
    - What are the response choices: yes/no, rating scale.
    - Are there biases in the design?
    - Do you have a budget to produce and analyze the survey?
  - **Write the questions keeping in mind the training goals** and keeping the wording simple. For Level 1, are you asking questions about training areas that you can actually change?
  - **Test your survey** on a few volunteers. They can let you know if items and responses are clear and reasonable and if the survey is appropriately formatted. Modify the survey as appropriate.
  - **Implement and evaluate** the survey. Make sure that you allot enough time for respondents to thoroughly fill out the survey. Record the responses, looking for trends.
- **Skill testing** in Fitzpatrick Level 2 can be done by a number of means
  - Each student is presented with a *checklist of tasks to perform*. Checklists are useful when a task can be broken down into a

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**Thought Problem 12.27: Survey Choices**

Surveys commonly ask for a rating from 1 to 10. If asking whether the materials were clear, are there really 10 levels of clear?

**Further Reading 12.28: Surveys**

An excellent resource for survey development and review can be found at [http://spss.com/PDFs/STIPr.pdf](http://spss.com/PDFs/STIPr.pdf).
standard list of specific actions and responses. Checklists can be made to lead the student through a task, giving them a means to review the process. An instructor can monitor proper performance. The instructor often sees only the endpoint and not the path or time required for the student to perform the task.

- The student is given a written exam, often requiring the user to perform a software task correctly in order to determine the correct answer to a question. Questions can be constructed to alter the context of the real-world situation and assess the student’s response. Questions must be carefully constructed to be clear and avoid bias.

- **Level 3, on the job skill testing** is more difficult to perform. Typical scenarios may include
  - A supervisor reviews a worker’s performance by observing the worker perform a task. Reporting relies on the supervisor’s memory and can be influenced by the work environment at the time of the testing. Some days are just more hectic than others.
  - A department quality assurance program is established to review the timeliness and accuracy of system use. This is only effective if there is an accurate and easily accessible audit trail of which user has performed each task. This also requires the ability for a systems person to create summary reports of job performance measures such as number of studies performed, QA errors, or turnaround times for specific users.

### Further Reading 12.29: Test Questions


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**12.6 Follow-Up**

- A training program should be an **on-going process** of training and evaluation.
- Use **survey results** to enhance the program for new users and new application training needs.
- Monitor **user performance** to assess when refresher training may be required.
Pearls 12.30

- User training is required before, during, and after any information system install or upgrade to assure data accuracy and quality throughout the hospital enterprise.
- Training programs should encompass well-defined learning objectives, training techniques that incorporate adult learning styles and assessment strategies that provide feedback on training success and program enhancement.
- The transfer of skills from the learning environment to the real-life clinical environment requires opportunities for training during simulation and consideration of the environmental factors that may impede skill transfer.
- Monitoring and testing of job skills, with the opportunity for retraining is required to assure consistent quality.
- It is difficult to perform a financial justification (ROI) of a training program. Therefore, training needs to be justified by improved quality of service.

Suggested Reading


Self-Assessment Questions

1. A good example of a learning objective for a training session on the QA module of a PACS system is: “At the completion of this course the user will be able to...”
   a. Define the image QA module.”
   b. Do image QA.”
c. Successfully resolve typical image QA issues using the QA module.
d. Avoid creating image QA issues.”

2. An important document which should be developed prior to designing the user training program is

a. User workflow
b. Cheat sheets
c. ROI
d. Translation tables

3. A training method that provides the advantage of having departmental user support persons long after go-live is

a. Vendor training of all staff individually
b. Train-the-trainers
c. IT training of department users
d. One-on-one training

4. The type of adult learner who benefits most from illustrations and cheat sheets during training is

a. Kinesthetic learner
b. Auditory learner
c. Visual learner
d. All of the above

5. An opportunity for training in a “real patient” environment is best provided during

a. One-on-one training
b. Group training in a classroom
c. User presentations in the classroom
d. Simulation prior to “go-live”

6. Formative assessments of learning progress are done to

a. Motivate learners
b. Enhance training programs
c. Improve the teaching process
d. All of the above

7. What are four processes that should be included in a training program?

8. How are learning objectives used in the design of a training program?
Chapter 13
Quality Assurance for Medical Imaging

Charles E. Willis

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13.1 Introduction

The goal of quality assurance (QA) is to maximize the efficiency of the imaging operation. Beyond the desire for efficient utilization of resources, QA is mandated in radiology by the American College of Radiology (ACR). Of course, compliance with standards of practice should not be the sole motivation for QA. Instead, QA should be a vehicle for providing the highest quality medical care. The totally digital radiology department offers a wonderful opportunity to exploit the features of automation toward that end.

Automation allows digital acquisition of images, facilitates the marriage of patient demographic and exam information with images, and provides rapid distribution of images and reports throughout the healthcare enterprise. This same automation compounds the consequences of human errors as only a computer can and contributes to errors and delay of diagnosis. Dependence of the automation system on the human operator, the complexity of the human–machine interfaces, and an insufficient level of integration among disparate automation subsystems place the quality of our product at risk. Improvement of quality depends on aggressive quality control (QC) processes and comprehensive QA oversight.

13.2 QA of Digital Imaging

13.2.1 Errors in a Digital Imaging System

- Humans have a well-established propensity for introducing random errors.
- Automation, on the other hand, produces systematic errors.
Humans use “inductive reasoning” and can work around machine errors. Machines do precisely as instructed, even when it is obviously wrong to a human.

- The human–machine interface creates a synergism that either makes up for the inherent deficiencies of humans and machines or aggravates the weaknesses of both parties.
- For example, increasing the complexity of the user interface increases human error exponentially.

13.2.2 False Sense of Security

- Electronic images are subject to deletion, misassociation of demographic and exam information, misrouting, and misinterpretation.
- Unlike film, the media that record electronic images are impermanent. Because of the huge capacity of electronic media, the loss of a single volume has greater consequences than that of a single film or even a single film jacket.
- Substandard electronic images can be proliferated throughout the hospital, while an individual bad film can easily be controlled.
- Substandard electronic images can disappear without a trace, complicating repeat analysis. Film usage provides a tell-tale signature of repeated exams in a conventional operation.

13.2.3 Errors Inside and Outside the Digital World

- Improperly calibrated acquisition devices, inappropriate examination technique, operator typographical errors, and transcriptionist errors are examples of errors in the translation of analog data into the digital world.
- Errors that occur within the digital world include inappropriate look-up-tables (LUTs), media failures, network failures, database failures, software bugs, improper association of exam and image information, and image retrieval and distribution failures.
- Improperly calibrated display devices, such as soft-copy monitors and laser cameras, are an example of errors that occur when trying to extract analog images for humans to use.

13.2.4 Consequences of Well-Known Errors

- The same errors that are well-known in conventional imaging also occur in digital imaging systems; however, the consequences of the errors can be either more or less severe.
While some mistakes can be readily corrected in the digital system, automation is not a panacea for bad practice. No algorithm exists to correct for patient motion, bad positioning, poor inspiration, incorrect alignment of x-ray beam and grid, wrong exam performed, or wrong patient examined. Image processing is a poor substitute for appropriate examination technique.

13.3 Processes and Products in the Imaging Department

13.3.1 Report Is the Product; Images Are Auxiliary

- If our intent is to improve the quality of our product, it is important to identify the product and all processes that contribute to its creation.
- In an imaging department, the primary product is the physician’s interpretation of the examination. In the most obvious case, this is a radiologist’s report that may be communicated directly to the referring physician.
- The images themselves are an auxiliary product that enables the interpretation and may serve as reference, for example, as a therapeutic guide, but become less significant once the interpretation is documented.

13.3.2 Process Mapping

- The sequence of processes that results in interpreted examinations is complex.
- Process mapping is a useful tool for identifying and understanding processes, as well as for determining interference with production.
- The details of process maps depend on the local clinical practice scenario as well as on the specific imaging systems and configuration.
- The intellectual exercise of constructing the process map is probably more valuable than the resulting map itself.
- Process mapping leads to process re-engineering to improve the efficiency of production or the quality of the product.

Key Concept 13.6: Radiologist Interpretation
The report is the primary product of the medical imaging operation. Images contribute to the interpretation process.

Synonym 13.7: Process Mapping
- Flowcharting
13.4 Measurable Indicators of Quality of Imaging Services

13.4.1 Availability and Quality of Images and Reports

- The quality of today’s image can have an impact on the clinical interpretation.
- Making today’s exam available to the radiologist is the gating event for diagnosis.
- The availability of prior exams and reports can also influence the diagnostic efficacy of today’s exam.
- Making the image and report available to the referring physician determines when indicated therapeutic actions can be initiated.
- The quality of the interpretation itself is the subject of active and ongoing efforts by the medical staff to monitor and improve diagnosis and treatment.
- National standards exist regarding the content of the report and communication of findings between radiologist and referring physicians.

13.4.2 Physical Aspects of Image Quality

- The quality of a diagnostic image can be described by three broad characteristics – **contrast, resolution, and noise**.
- **Artifacts** are another broad category of features in the image that can adversely affect the diagnostic efficacy of the exam.
- Factors that influence the quality of the image include the fundamental capabilities and limitations of the imaging equipment, the condition of the equipment, such as, how it is calibrated, configured, and maintained, and how the equipment is operated.
13.4.3 Ionizing Radiation Dose

- Another major consideration for modalities that involve ionizing radiation is the patient dose required to produce the image.
- Density, the usual aspect of conventional image indicating under-exposure or over-exposure, is an adjustable parameter in electronic imaging systems, and therefore is not useful for monitoring exposure factor selection.
- Specific information about the amount of radiation used to acquire each image is contained in meta-data accompanying the DICOM image.
- Some acquisition modalities have the capability to monitor and analyze this information.
- Interpretation of these data may require assistance from a medical physicist.

13.4.4 Electronic Display Quality

- The quality of the electronic image depends on how it is displayed.
- Much of the QC effort in conventional departments is devoted to consistent automatic processing of photographic film.
- Recent standards address QC of multiformat cameras and laser film printers and electronic image displays.
- Electronic images depend on cathode ray tube (CRT) or liquid crystal display (LCD) monitors that degrade over time.
- Digital images can also be flawed if they use an inappropriate display look-up-table (LUT).
- Digital test patterns can make display problems obvious.

13.4.5 Repeated Images

- The percentage of images that must be repeated (repeat rate) is a gross indication of the quality of imaging services.

13.4.6 Discrepancies in Demographic and Exam Information

- Patient demographic and exam information are associated with each image that is acquired.
If the demographic and exam information in the medical imaging system does not match information in the radiology information system (RIS), then the image is classified as an exception.

Exceptions may be hidden from view by physicians, or may be tabulated in an area where they would not be normally viewed.

Exceptions must be manually corrected to reconcile their data with the RIS.

DICOM modality worklist management (MWL) reduces the number of exceptions, but introduces new errors, such as misidentification.

### Thought Problem 13.14: Repeat Rate

Without more detailed analysis, the repeat rate does not suggest specific actions that need to be taken to improve services. For example, in the early deployment of electronic imaging systems, dramatic reductions in repeat rates were reported and attributed to the electronic systems broader tolerance of over-exposure and under-exposure. An alternative explanation was that the technologists were using considerably higher doses than necessary to perform the examination producing images with much less noise that was more visually acceptable to the radiologist. Another possibility is that the technologists had no confidence that repeating the exam would result in improved images. It is possible that the technologists simply deleted many of the nondiagnostic electronic images to prevent them from being released to the physician. Yet another plausible explanation is that in electronic imaging systems, the expedited availability of images becomes the number one priority and image quality and patient dose are subordinated. A high reject rate, on the other hand, might be the result of inordinate emphasis on image quality.

### 13.4.7 Misidentification

- The image must also be accurately and unambiguously identified in order to be of immediate and future clinical value.
- In an electronic imaging system, misidentification of images should be treated as a QA event.

**Definition 13.12: Reject**

An image that is not useful for care of the patient. Includes test images and nondiagnostic images.

**Definition 13.13: Repeat**

Duplicate image obtained because original image was substandard or lost.

**Key Concept 13.15: Repeated Images**

Repeating images extends the time needed to complete an exam and delays interpretation. The imaging resource is occupied longer than necessary. It also requires additional radiation exposure to the patient.
Misidentified electronic images may be associated with the wrong patient, or may be sequestered or otherwise unavailable for viewing, causing a delay in diagnosis.

13.5 Mechanisms for Improving Performance in the Digital Department

An effective QA program is founded on acknowledgment of the errors that will occur, institution of processes to avoid, detect, and correct errors, and enforcement of these processes. Documentation of errors serves as the basis for root cause analysis and as an objective assessment of progress.

13.5.1 Selection of Indicators and Action Limits

- It is impractical to measure every possible indicator of quality.
- For this reason, specific indicators are selected that are expected to be sensitive to variations in quality of service, and these are measured periodically.
- The interval of measurement should be slightly more frequent than the incidence of corrective action.
- If every measurement yields an inconsequential result, then the interval between measurements can be prolonged.
- On the other hand, if every measurement dictates a correction, the interval should be reduced.

13.5.2 Timeline Analysis

- Most electronic imaging services have a radiology information system (RIS) that is an automated system for scheduling and tracking the progress of examinations.
The RIS records the time when the exam is scheduled, when the patient arrives for the exam, when the exam is completed, and when the report is dictated, transcribed, and approved.

**Interrogating the RIS** produces reports that can be analyzed to reveal the contribution each process makes to the overall turnaround time for an exam. Interpretation of the timeline can suggest modifications in resources to expedite the slowest steps.

The image database may also provide data about receipt and viewing of images that can be coupled with RIS reports to identify areas for improvement.

### 13.5.3 Reject Analysis

- Repeated examinations represent inefficiency in imaging operations and additional ionizing radiation exposure to patients.
- Documenting the reason for the repeated exam is best done concurrently with ongoing operations.

**Our Experience 13.20: Reject Analysis**

In 2002, Texas Children’s Hospital initiated a program for documenting rejected images. The demographic information was modified by the technologist supervisor and the rejected images were archived to the PACS. Subsequent analysis of the reasons and responsibility for rejects had some surprising results.

The causes, frequency, and proportions of rejected digital images are comparable to those experienced in a conventional screen-film setting. Positioning errors cause about half of all repeated images. The group of technologists with the largest number of rejected images were agency techs, temporary employees who were unfamiliar with the equipment and pediatric patients. Their performance improved over time.

Another group of technologists with high repeat rates were supervisors! Further investigation revealed that supervisors were called on to perform technically difficult exams that frontline techs were unable to do. The supervisors also had a higher standard of quality for their own exams.

**Key Lessons Learned**

- Rejected images in a digital department are caused by the same errors as in a conventional department.
- Positioning errors are the biggest cause of repeats.
- Inexperienced technologists have the highest reject rates, and therefore should be the focus of training and supervision.
- High reject rates can also be attributed to technically difficult examinations.
• Automation should facilitate documentation of repeated exams, in fact some of the electronic imaging systems available today are designed to accommodate reject analysis.
• Retakes need to be assigned to categories, such as positioning, patient motion, over-exposure, under-exposure, etc.
• It is important to record the exam and view being performed, the technologist performing the exam, and the imaging equipment used.
• In this way, remedial training or equipment service is indicated.
• The total volume of exams and views should be counted and used as the denominator in the reject rate.

13.5.4 Reliability Analysis

• In order to maintain continuity of clinical services, it is valuable to perform a reliability analysis of the electronic imaging system.
• In the analysis, single points of failure are identified.
• A local failure of one of these components has a global effect on other components of the system.
• Reliability of the entire system can be improved by building redundancy into the system.
• It is worthwhile to identify reasonable scenarios that involve the loss of components or utility services and to consider the effects on the imaging system.
• Planning and rehearsing downtime procedures in advance of a catastrophe can ensure the availability of images for clinical operations.

Further Reading 13.21: Reject Analysis

Further Reading 13.22: Reliability Analysis

13.5.5 Radiologist Image Critique

• Radiologist feedback is a driving force in effective QA.
• This feedback is most effective when delivered contemporaneously.
• To solicit this feedback, we developed codes for the radiologist’s critique that can be dictated and transcribed into our RIS.
• These codes include comments on both image quality and availability.
13.5.6 Training and Orientation

- An effective QA program must incorporate training and orientation programs.
- Applications training provided by the vendor is not sufficient.
- Local policies and practice must be developed, and these must be communicated to human operators of the system.
- These policies must be documented, reinforced periodically, and strictly enforced.
- We have found that Clinical Competency Criteria checklists are helpful in standardizing and documenting basic proficiency training.
- It is important to recognize that one size does not fit all: training should be tailored for technologists, radiologists, referring physicians, clinical engineers, and imaging informatics personnel.

13.5.7 Service Support

- Any QA program is incomplete without considering service support.
- Like conventional operations, the electronic department must plan for service interruptions.
- It is important to build in redundancy in the electronic components, which may be more expensive than their conventional analogs.
- To minimize downtime, it is wise to maintain a stock of on-site spare parts, especially for displays and long-lead items for devices that are heavily utilized.
- When a hospital has competent biomedical engineering staff, it is worthwhile considering first-call participation in service events.
- Preventive maintenance (PM) is always preferable to unscheduled maintenance.
  - In this regard, calibrations should be performed on-schedule.
  - Operators also have a responsibility to perform PM tasks: they should clean and inspect equipment, and document what they do.
  - PM should be scheduled at the convenience of the clinical operation, not the service provider.
- In an electronic department, software upgrades should be regarded as major service events where downtime is indeterminate and proper function must be re-verified.
- Notification of users when a service outage occurs and when service is restored is critical to maintaining confidence in service support.
13.6 Roles and Responsibilities for QA

13.6.1 Radiologic Technologist

- In addition to performing the examination, the technologist, or technologist supervisor, in an electronic department has to assume responsibility for the delivery of all images to the physician.
- This implies a process and mechanism for verifying arrival of all images and a mechanism for detecting and correcting errors in delivery.
- In a department with a large workload, the QA activity may demand one or more dedicated QC technologists.

Key Concept 13.23: Radiologic Technologist

In an electronic department, the RT is not only responsible for performing the exam and producing acceptable images but also for assuring the delivery of all images to the physician for viewing.

13.6.2 Imaging Informatics Professional

- Involved in collecting and analyzing QC data, i.e., data mining
- Assist in correcting errors
- Can assist in automating QC processes
- Assist in training of personnel on the use of automated systems
- May be involved in troubleshooting and service support

13.6.3 Medical Physicist

- The medical physicist has comprehensive, practical knowledge of imaging technology and workflow and is the sole member of the team who has primary interest in the quality of the imaging operation.
- The department should utilize the medical physicist as a QA resource.

13.6.4 Radiologist

- Active and enthusiastic support of QA by radiologists is absolutely required for an effective program.
- Radiologists control resources and priorities in imaging departments.
- Radiologists must demand accountability for image quality and availability.
13.6.5 Radiology Administrator

- Must appreciate value of QA in radiology operations
- Must allocate resources to the QA effort
- Must enforce QA policies and procedures
- Must arrange for training of personnel
- Must coordinate QA efforts

13.6.6 QA Committee

- Includes all stake holders in radiology operations (see above)
- Meets periodically to review QC data and QA incidents
- Codifies QA and QC plans, activities, and responsibilities in policies and procedures
- Commits resources to QA activities

Pearls 13.24

- Knowledge by department personnel of the consequences of errors, non-judgmental reporting systems, and a sense of personal responsibility for timely and accurate delivery of images are keys to effective improvement in digital services.
- If you do not measure performance, you have no means to gauge improvement, and you will be sorry in the long run.
- QA costs resources; you must believe that this investment is insignificant compared to the benefits.
- Collecting and analyzing QC performance data serve no purpose unless it is widely communicated and used to target resources for improvement.
- Hospital staff is only capable of providing the lowest level of quality that is tolerated by radiologist.

Suggested Reading

Self-Assessment Questions

1. Who has the first opportunity to detect and correct errors?
   a. Radiologist
   b. Medical physicist
   c. Imaging informatics professional
   d. Radiologic technologist
   e. Radiology administrator

2. Who is the person who has the last opportunity to detect and correct an error before it can affect patient care?
   a. Radiologist
   b. Medical physicist
   c. Imaging informatics professional
   d. Radiologic technologist
   e. Radiology administrator

3. Who sets the standard for quality in an imaging operation?
   a. Radiologist
   b. Medical physicist
   c. Imaging informatics professional
   d. Radiologic technologist
   e. Radiology administrator

4. Which of the following is not a measurable indicator of quality?
   a. Availability of images and reports
   b. Single points of failure
   c. Ionizing radiation dose
   d. Repeated images
   e. Exceptions

5. What is the single best method for understanding radiology operations?
   a. Reliability analysis
   b. Reject analysis
   c. Task allocation matrix
   d. Policies and procedures
   e. Process mapping

7. List three types of QA data that could be obtained by an imaging infor-
   matics professional by data mining of the RIS or image database.

8. A radiologist is complaining about the appearance of images on his electro-
   nic display. What are three possible causes? Explain how you would isolate
   and troubleshoot the problem.

9. From the text above, compile a list of 10 components of a QA program.

10. List three characteristics of electronic images that make electronic QC
    different from conventional screen-film QC.
Chapter 14
Data Storage and Disaster Recovery

Edward M. Smith

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14.1 Philosophy of Storing Electronic Protected Health Information (ePHI)

- The storage and retrieval of ePHI is a multifaceted function ranging from within the healthcare facility and related off-site practices to the referring physician’s office to the patient and eventually to regional and national depositories.
- Establish purchasing and interoperability standards for all hardware, software, and applications that touch the institution’s digital environment that are mutually acceptable to all parties within the healthcare community.
- Currently, images (objects) consume 95% or more of the storage requirements versus 5% or less for data (databases). This may change if clinical images are stored in a lossy compressed format rather than in a lossless compressed format. Lossy compressed storage is beginning to be implemented in Canada as well as by some groups in the United States.
- Estimating storage requirements is at best an educated guess due to new innovations generating increasingly larger amounts of information and the expanding digital environment in healthcare.
- Storage management components should be purchased separately from the clinical and administrative applications to reduce cost and ensure vendor independence while requiring interoperability between all components in the digital environment.
- All parties must work together to develop workarounds to maintain administrative and clinical operations during periods of system unavailability.

14.1.1 Enterprise Storage Versus Departmental Silos of Storage

- Isolated silos of departmental storage are difficult to manage.
- Divorcing storage components from administrative and clinical applications:

Key Concept 14.1: Image Compression

The image format from which the diagnosis is made MUST be the format in which the study is stored.
– Allows administrative and clinical departments to acquire applications that optimize workflow and productivity.
– Independence from application vendor by eliminating proprietary storage formats, thus minimizing future cost of information migration.
• Reduce cost of hardware, software, licensing, and maintenance fees plus personnel cost.
• Provides an integrated storage and storage management system.
• Provides high availability and redundancy of information at a reduced cost.
• Satisfies state and federal retention periods for medical information and HIPAA requirements in the most cost-effective manner.

Further Reading 14.2: Economics of Enterprise Storage

• Cecil RA. Solve the enterprise archive puzzle. Imaging Economics. 2007 Jan; 38–43.
• Langer SG. Global PACS Archiving. Enterprise Imaging and Therapeutic Radiology Management. 2008 Sep; 61–7. (Note: contains information on current storage systems.)
• Smith EM. Integrated implementation revamps information storage. Diagnostic Imaging. 2005 Jan; 39–43.
• Smith EM. Storage management: one solution doesn’t fit all. Imaging Technology News. 2004 Nov/Dec; 80–3.

14.1.2 Responsibility of Storage Management

• Information Technology Department is primarily responsible for storage management including funding, providing necessary infrastructure, hardware and software, managing and meeting the administrative and clinical departments’ requirements including the following:
  – Storage requirements.
  – Periodically upgrading hardware and software due to technological obsolescence and migrating information as required.
  – 24 hours by 7 days accessibility to all information.
  – Meeting required clinical and administrative response time for queries of information.
  – Adhering to HIPAA and other mandated federal, state and local security, and retention requirements for healthcare-related information.
  – Providing required disaster recovery (DR) and business continuance (BC) including timely backup and replication of required information.
• Administrative and Clinical Departments are responsible for
  – Working with IT to ensure their applications adhere to the purchasing and interoperability standards mutually agreed upon.
– Being realistic in their requirements for response times for information queries.
– Estimating storage requirement for a 12- to 18-month period.

- **Chief Financial Officer** understands that
  – Storage management is an on-going cost and provides necessary funding.
  – Life cycle of many of the components is 3–5 years due to technical obsolescence.

### 14.1.3 Economics of Storage Management

- The cost of storage management is a recurring cost and must be budgeted for annually
- Cost of storage management includes
  – Hardware, infrastructure, and software
    - Initial cost
    - Maintenance and licensing fees
    - Replacement cost due to technological obsolescence
  – Storage **media cost** that is approximately 5–10% of the total cost.
  – Personnel
  – Utilities – power, HVAC, etc.
  – Cost for space used in secure datacenter.
  – Costs related to data backup and replication of data, business continuity, disaster recovery.
  – Data migration related to technology obsolescence of storage media and related hardware.
- To minimize the cost of storage management
  – Enterprise storage is mandatory – eliminate all isolated silos of storage.
  – The storage management design must be scalable, consist of nonproprietary components, and adhere to standards.
  – Purchase media based on projected needs for periods of **12–18 months** since storage and cost per TB decrease with time.
  – Purchase subsystems and associated media based on performance requirements of applications.

### 14.2 Datacenters

- The IT department is responsible for funding, managing, and supporting the datacenter.
• Provide power and cooling for a contemporary datacenter with high-density computing resources is a significant cost.
• Healthcare facilities computing resources should reside in a secure datacenter providing a level of availability of medical information that meets or exceeds the clinical requirements of the institution.
• Clinical departments must specify the characteristics of the computing resources and availability requirements for medical information meeting the clinical requirements.

14.2.1 Tier Rating of Datacenters

• The Uptime Institute provides industry recognized and accepted standards for high-density computing and mission critical facilities in a vendor neutral manner.
• The primary attribute of the Tier rating of a datacenter is the availability of the computing resources it contains.
• Tier rating may be too expensive and rigorous for many healthcare facilities, but provides guidelines to strive for and use in selecting a datacenter to outsource some aspect of their computing resources or disaster recovery:
  – Tier 1 datacenter has no redundant components such as on-site generator, UPS, fire suppression system, HVAC, etc. When there is a planned or unplanned outage, availability is affected.
  – Tier 2 datacenter has redundant components, but only a single-distribution system. This provides availability for planned outages, but not for unplanned outages when availability will be affected.
  – Tier 3 datacenter has redundant components and distribution systems plus dual public power supplies that provide the capability to operate self-sufficiently. All computer resources have two independent power sources. These features provide system availability for unplanned outages and during routine maintenance.
  – Tier 4 datacenter has all the features of Tier 3 plus the topology is configured such that any single component or distribution failure has no negative impact on availability (Table 14.1).
14.3 Types of Medical Data

From a storage perspective, imaging data can be divided into

- Data that may change after they are stored and are thus managed as a variable content file (VCF).
- Data that will not change once they are stored and are thus managed as a fixed content file (FCF).

14.3.1 Variable Content Files (VCF)

- VCF or transactional data consist primarily of databases that comprise approximately 5% of the total stored image-related data.
  - Examples: radiology information system (RIS), hospital information system databases, and the demographic database of the PACS.
- The frequency of read/write commands to the database dictates the storage technology used to manage and replicate or backup the database.

14.3.2 Fixed Content Files (FCF)

- FCF imaging data consist primarily of DICOM objects such as images, structured reports, and curves that comprise approximately 95% of the total stored image-related data.
- The typical storage configuration for image data is
  - On the modality generating the images for one or more days.
  - The modality immediately forwards a copy of the images to “Tier 1 storage” (on-line storage) and possibly to one or more workstations for emergent studies.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Tier 1</th>
<th>Tier 2</th>
<th>Tier 3</th>
<th>Tier 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year first deployed</td>
<td>1965</td>
<td>1970</td>
<td>1985</td>
<td>1995</td>
</tr>
<tr>
<td>Single points of failure</td>
<td>Many + human error (HE)</td>
<td>Many + HE</td>
<td>Some + HE</td>
<td>Fire, EPO* + some HE</td>
</tr>
<tr>
<td>Planned maintenance shut-downs</td>
<td>2 per year at 12 hours each</td>
<td>3 per 2 year at 12 hours each</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Representative site failures</td>
<td>6 over 5 years</td>
<td>1 every year</td>
<td>1 every 2.5 years</td>
<td>1 every 5 years</td>
</tr>
<tr>
<td>Annual downtime due to site unavailability</td>
<td>28.8 hours</td>
<td>22 hours</td>
<td>1.6 hours</td>
<td>0.8 hour</td>
</tr>
<tr>
<td>Availability based on site caused downtime</td>
<td>99.67%</td>
<td>99.75%</td>
<td>99.98%</td>
<td>99.99%</td>
</tr>
</tbody>
</table>

* Emergency power off
Tier 1 storage is managed by the PACS and is typically configured to store between 3 and 15 months or more studies depending on the clinical requirements.

The PACS verifies the information in the DICOM header of the study against the information in the RIS for that study then.

The PACS forwards a copy of the study to the “Tier 2 storage” (long-term storage) where it is retained for the legal life of the study and a copy is either:

- Copied to a storage system at a remote location.
- Copied to tape or other media and carried off-site for “Tier 3 storage” (disaster recovery) and retained for the legal life of the study.

Initially, four copies of a study exist until eliminated on the modality
- Then, three copies until eliminated from Tier 1 storage.
- Finally, a copy will remain on Tier 2 and Tier 3 storage.

14.4 Storage Requirements for ePHI

14.4.1 Health Information Portability and Accountability Act (HIPAA)

The security regulations of HIPAA effective April 21, 2005 cover the confidentiality, integrity, and availability of ePHI.

PHI identifies an individual and relates to that individual.
- Past, present, or future physical or mental health
- Provision for healthcare or
- Past, present, or future payment for healthcare

HIPAA covers ePHI stored on any type of storage media including
- Portable computers and related devices
- Transmitted electronically via the Internet
- E-mails or other related methods

Confidentiality is the assurance that ePHI is available to only authorized persons or organizations to view that ePHI.

Requires ePHI that is stored on media or transmitted electronically be encrypted
- Both when in transit and stored on physical media.
- When it can be accessed by unauthorized individuals or organizations.
  - Example: individuals in a healthcare facilities datacenter

Further Reading 14.4: HIPAA

Chapter 18 provides detailed information on Regulatory Policies
Availability is the assurance that systems responsible for delivering, storing, and processing ePHI are accessible in a timely manner by those who need them under both routine and emergency situations.

- HIPAA requires that two copies of ePHI must exist, so if one copy is accidentally destroyed during its legal life (retention period), a second copy will be available in a secure and accessible location.

Integrity is the assurance that ePHI is not changed unless an alteration is known, required, documented (audit trial), validated, and authoritatively approved.

- When ePHI has been authoritatively approved, it should be stored electronically in a format that inhibits unauthorized alterations, e.g., Write Once, Read Many (WORM).

14.4.2 Storage Requirements for Clinical Studies

- General radiology
  - **Typical uncompressed storage requirements** by modality per study
  - Excludes CTA, 3 Telsa MR, MRA, PET/CT, and mammography studies (Table 14.2 and 14.3)

- Women's imaging
  - **Digital mammography**
    - Amorphous silicon, indirect DR – 100 micron resolution
    - Amorphous selenium, direct DR – 70 micron resolution

<table>
<thead>
<tr>
<th>Modality</th>
<th>Image size</th>
<th>Per study basis</th>
<th>Uncompressed MB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of images</td>
<td>X</td>
<td>Y</td>
</tr>
<tr>
<td>CR</td>
<td>2,000</td>
<td>2,500</td>
<td>2</td>
</tr>
<tr>
<td>DR</td>
<td>3,000</td>
<td>3,000</td>
<td>2</td>
</tr>
<tr>
<td>CT</td>
<td>512</td>
<td>512</td>
<td>2</td>
</tr>
<tr>
<td>Multi-slice CT</td>
<td>512</td>
<td>512</td>
<td>2</td>
</tr>
<tr>
<td>MR</td>
<td>256</td>
<td>256</td>
<td>2</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>640</td>
<td>480</td>
<td>1*</td>
</tr>
<tr>
<td>Nuc Med</td>
<td>256</td>
<td>256</td>
<td>2</td>
</tr>
<tr>
<td>Film Digitizer</td>
<td>2,000</td>
<td>2,500</td>
<td>2</td>
</tr>
<tr>
<td>Digital Fluoro</td>
<td>1,024</td>
<td>1,024</td>
<td>1</td>
</tr>
<tr>
<td>Rad Angio</td>
<td>1,024</td>
<td>1,024</td>
<td>1</td>
</tr>
</tbody>
</table>

* 3 Bytes for color

**Definition 14.5: Retention Period**

Time, mandated by federal, state, or local statute, that medical information must be retained in its original and legal form.
**Table 14.3** Typical uncompressed storage requirement per 100,000 general radiology studies (Excludes CTA, 3 Telsa MR, MRA, PET/CT and mammography studies)

<table>
<thead>
<tr>
<th>Modality</th>
<th>% of Studies</th>
<th>Ave. MB/Study</th>
<th>GB/Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angiography</td>
<td>3</td>
<td>15</td>
<td>45</td>
</tr>
<tr>
<td>CR and DR</td>
<td>64</td>
<td>42</td>
<td>2,688</td>
</tr>
<tr>
<td>CT</td>
<td>20</td>
<td>52</td>
<td>1,040</td>
</tr>
<tr>
<td>MR</td>
<td>5</td>
<td>39</td>
<td>195</td>
</tr>
<tr>
<td>Nuclear Medicine</td>
<td>3</td>
<td>1.3</td>
<td>3.9</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>5</td>
<td>18</td>
<td>90</td>
</tr>
<tr>
<td>Total TB per 100,000 studies</td>
<td></td>
<td></td>
<td>4.1 TB</td>
</tr>
</tbody>
</table>

- CR – 50 micron resolution – **storage requirement 4 times greater than 100 micron resolution**
- Average mammography storage requirements based on 70% large cassette/paddle and 30% small cassette/paddle and 4 images for screening and 6 images for diagnostic studies (Table 14.4)

**Breast MR**
- Storage requirements vary widely depending on
  - Image size, number, and slice thickness
  - Protocols, sequences, and modality vendor
- Protocols requiring contrast increase storage requirements significantly
- Average breast MR storage requirements
  - Represents protocols from Aurora, GE, and Siemens (Table 14.5)

**Table 14.4** Average mammography storage requirements by type of detector

<table>
<thead>
<tr>
<th>Resolution (microns)</th>
<th>Study type</th>
<th>Uncompressed storage requirement (MB)</th>
<th>2.5–1 Lossless compressed storage requirement (MB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>Screening</td>
<td>197</td>
<td>79</td>
</tr>
<tr>
<td>50</td>
<td>Diagnostic</td>
<td>296</td>
<td>118</td>
</tr>
<tr>
<td>70</td>
<td>Screening</td>
<td>96</td>
<td>38</td>
</tr>
<tr>
<td>70</td>
<td>Diagnostic</td>
<td>144</td>
<td>58</td>
</tr>
<tr>
<td>100</td>
<td>Screening</td>
<td>52</td>
<td>21</td>
</tr>
<tr>
<td>100</td>
<td>Diagnostic</td>
<td>78</td>
<td>31</td>
</tr>
</tbody>
</table>

**Table 14.5** Representative Storage Requirement for Breast MR

<table>
<thead>
<tr>
<th>Views</th>
<th>No. of sites</th>
<th>Uncompressed (MB)</th>
<th>Mean – Lossless compressed 2.5–1 (MB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial w/o contrast</td>
<td>5</td>
<td>63–132</td>
<td>98</td>
</tr>
<tr>
<td>Axial with contrast – typically 5 sequences</td>
<td>5</td>
<td>223–336</td>
<td>294</td>
</tr>
<tr>
<td>Saggital</td>
<td>2</td>
<td>42</td>
<td>42</td>
</tr>
<tr>
<td>Typical lossless storage requirements</td>
<td></td>
<td></td>
<td>17</td>
</tr>
</tbody>
</table>
14.5 Retention and Destruction Requirements for ePHI

14.5.1 Retention Requirements for ePHI

- Depending on the local, state or federal statutes, ePHI must be retained in its original form (from which diagnosis was made) for a period of from **5 to 7 years or longer**.
- Healthcare facilities should establish and document retention periods for all types of ePHI based on the requirements imposed by various statutes.
- Images stored for purposes of complying with regulatory backup (DR) requirement must be of the same quality as images used for diagnostic purposes.
- ePHI for minors may have to be retained until the individual reaches the age of 21 or beyond, depending on when the ePHI was acquired.
- Regulations exist, typically state statute of limitations, that require ePHI be retained for usually a period of 2 years after the death of a person.

**Key Concept 14.6: Retention**

Retention period for ePHI varies and
- Is dependent on type of ePHI
- Is dependent on age of individual
- Is specified by federal statute
- Varies by state and type of provider
- Complies with state’s statute of limitations

14.5.2 Film Screen and Digital Mammograms

- Retained for not less than **five (5) years**.
- Not less than **ten (10) years** if no additional mammograms of patients are performed at the facility performing the study.
- Longer if mandated by federal, state, or local statutes.
- Digitized film screen mammograms cannot be used for retention purposes (not original and legal), but can be used for comparison with current digital mammograms.
- Recommended that computer-assisted diagnosis (CAD) reports be retained as part of the mammography study.
- Lossy compressed mammograms cannot be used for retention purposes.

**Further Reading 14.7: Retention of Mammograms**

- Federal Register 900.12(c)(4)(i),(ii)

14.5.3 Destruction Requirements for ePHI

- ePHI must be destroyed so there is no possibility of reconstructing the information.
• Resulting from the complex rules governing retention of ePHI, automation of its destruction is not possible currently.

• **The most cost-effective solution to manage outdated ePHI may be permanent retention.**

• Destruction of ePHI must be documented including
  – Date of destruction
  – Method of destruction
  – Description of disposed records
  – Inclusive dates covered
  – Statement that the records were destroyed in the normal course of business
  – Signature of individual supervising and witnessing the destruction

• Magnetic and optical media
  – CD, DVD, and other magnetic or optical media should be shredded
  – Degaussing is the preferred method to destroy data on magnetic disk or tape

14.6 Storage Technology

14.6.1 Types of Storage Media

• Parameters used to select storage media
  – **Functionality** – does it meet the clinical requirements for the application – response time to read (retrieve) and write information and storage capacity.
  – **Longevity** – how long will the media and the components used to read and write to the media be available and be supported (technology obsolescence), will there be backward compatibility or will information have to be migrated? Information migration is expensive and can be time consuming. For most media,
technical obsolescence is between 3 and 6 years depending on when it is purchased in its life cycle.

- Total cost of ownership (TCO) of the entire storage management system for the storage media used – is the total cost of purchasing and supporting the storage management system and includes hardware, software, maintenance and licensing fees, personnel, utilities, space, and information migration costs.

- Cost – media is typically less than 5–10% of the TCO of the storage management system.

- **Durability** – information stored on media must be accessible for a long period of time, factors that affect durability include wear and tear from read/write components, temperature, and humidity changes, etc.

- **Compliance** features – HIPAA requirements regarding immutability and integrity of ePHI, e.g., storing in WORM format.

- Remove ability – media that can be removed from the read/write source. Evaluate the pros and cons for the particular application.

- Storage media cabinets should have redundant power supplies and fans to minimize system failures.

**Optical media**

- **General**
  - Used primarily to provide a transportable copy of individual patient study and as a low-cost, long-term storage, and disaster recovery media.
  - Inferior performance characteristics to spinning magnetic disk with respect to read/write speed capabilities and storage capacity.
  - Optical media maintains integrity of stored information for the long term if properly handled, but limited useful life of 6 years due to technology obsolescence.
  - Data are typically written in Write Once Read Many (WORM) format that is advantageous for purposes of long-term storage and HIPAA compliance.

- **Compact disk (CD)** used primarily as transportable media for an individual patient study stored in DICOM Part 10 format as WORM with a DICOM viewer.
  - CDs are available as CD-R, WORM version, and CD-RW, a re-writable version that **MUST NOT** be used for storage of medical information, ePHI.
  - Storage capacity is up to 700 MB.

**Further Reading 14.11: Optical Media**

Digital versatile disk (DVD) is also available as DVD-R and DVD-RW and only the DVD-R version should be used to store medical information, ePHI.

- Single-sided, single-layer DVD will store up to 4.7 GB and the single-sided, double-layer will store 8.5 GB.
- These are typically used for inexpensive long-term storage or DR within a robotic storage system.

Other versions of proprietary optical disk format include

- Ultra density optical (UDO) from Plasmon can store 120 GB.
- Plasmon is no longer in operation. Support for UDO is available from other vendors, but robotic device may not be available.
- Blu-ray is an optical disk format supported by a large group of vendors that can currently store 50 GB.

Holographic optical storage is a 3D version of the optical storage disk that has been in development for many years and is just beginning to be commercialized.

- It has the potential to store 3.9 TB at very high-transfer rates approaching 120 MB/seconds.

Magnetic tape media.

- Use of magnetic tape is decreasing, and when used, it is for Tier 3 storage (disaster recovery), for backup of databases and infrequently as an inexpensive Tier 2 storage system.
- The tape drives that read/write to the media are separate elements and are typically obsolete in 5–6 years while the media has a longer life expectancy depending on usage and proper handling.
- Reasons for the decreasing usage of tape include time to restore (access) data, inherent failure rate of tape restorations, serial transfer medium versus random for disk.
- Tape is available in many physical (1.58–19 mm wide) and storage (linear and helical) formats.
- Tape is available in uncompressed storage capacity up to 1 TB and lossless compression ratios around 2:1.
- Data can be written to tape in WORM format.
- Tape cost advantage over disk is decreasing when total cost of ownership (TCO), accessibility, and reliability of the storage system is considered.

Spinning magnetic disk (hard disk drive – HDD).

- Performance
  - To decrease time to access data, increase rotational speed range from 5,400 to 15,000 rpm.
To increase throughput and storage capacity, increase media storage density, as of July 2008 the highest capacity HDD was 1.5 TB.

**Redundant Array of Independent Disks (RAID)**

- RAID, except for RAID 0, writes parity data across the array of disks, which are organized so that the failure of one disk, two for RAID 6 and 10, in the array will not result in loss of all the data. A failed disk can be replaced by a new one, and the data on it reconstructed from the remaining data and the parity data. As a result of this redundancy, less data can be stored in the array.
- Selection of the appropriate RAID level depends upon the application, degree of protection against data loss, storage capacity, and performance (number of write/read per second).
- RAID is not a substitute for backing up data on another media located remotely from the RAID.
- RAID 0 – data are striped across several disks to improve performance and obtain 100% storage capacity. No redundancy is provided, if one disk all data are lost.
- RAID 1 – two groups of one or more disks each, store exactly the same data. No data will be lost as long as one group of disks survives.
- RAID 5 – (striped disk with parity) combines three or more disks in a way that protects data against loss of any one disk. Storage capacity is reduced by one disk. A “hot spare” disk should be added to the array so data can be automatically restored. If an additional disk fails while data are restored, data in the entire array can be lost.
- RAID 6 – (striped disk with dual parity) can recover if two disks in the array are lost. A “hot spare” disk should be added to the array so data can be automatically restored.
- Raid 1 + 0 or RAID 10 – uses both stripping and mirroring, consists of a striped set of mirrored subsets, provides fault tolerance and improved performance.
- Comparison of RAID levels (Table 14.6).

**Further Reading 14.14: CAS**

- www.en.wikipedia.org/wiki/content_addressable_storage
is used for fixed content files of ePHI to meet regulatory requirements.

– Massive array of idle disks (MAID) – is designed for Write Once, Read Occasionally (WORO) applications.
  • In MAID, drives are not continuously spinning, but only spun up on demand.
  • MAID has increased storage density, and decreased cost, electrical power and, cooling requirements compared to RAID.
  • Compared to RAID, MAID has increased latency, significantly slower throughput, and provides little or no redundancy.
  • SATA drives are used in this application.
  • Primary use is for DR (Tier 3) or Tier 2 storage if Tier 1 storage contains sufficient capacity to respond to 99% or more of the on-line clinical retrieval requirements.
  • MAID can supplement or replace tape libraries.
  • Solid state media is currently used in “memory sticks” or “flash drives” and may begin to replace spinning magnetic disks in the future. At present, the cost per GB is approximately $2 versus 30 cents for disk storage (Table 14.7).

<table>
<thead>
<tr>
<th>Table 14.6 Characteristics of RAID levels in common use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feature</td>
</tr>
<tr>
<td>Minimum number of Drives</td>
</tr>
<tr>
<td>Data Protection</td>
</tr>
<tr>
<td>Read Performance</td>
</tr>
<tr>
<td>Write Performance</td>
</tr>
<tr>
<td>%Storage Utilization</td>
</tr>
<tr>
<td>Typical applications</td>
</tr>
</tbody>
</table>

Further Reading 14.15: MAID

As the quantity of digital information grows in the healthcare environment, the requirement for a secure, highly available, and cost-effective storage management solution becomes imperative. Backup and DR are also dependent on the storage management solution selected. Factors to consider in this selection process include:

- **Capacity** – amount and type of data (file level or block level) to be stored or shared

### Table 14.7 Comparison of storage media

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Magnetic Disk</th>
<th>Optical Disk</th>
<th>Magnetic Tape</th>
</tr>
</thead>
<tbody>
<tr>
<td>Write/Read</td>
<td>Random</td>
<td>Write serial, read random</td>
<td>Serial</td>
</tr>
<tr>
<td>Study retrieval time</td>
<td>Milliseconds</td>
<td>Seconds</td>
<td>Tens of seconds</td>
</tr>
<tr>
<td>Use</td>
<td>On-line immediate access, departmental or enterprise storage/archive, disaster recovery</td>
<td>Individual patient study and departmental or enterprise storage/archive, disaster recovery</td>
<td>Departmental or enterprise storage/archive, disaster recovery</td>
</tr>
<tr>
<td>Uncompressed storage capacity</td>
<td>Up to 1 TB per disk, access time will increase with increasing disk capacity</td>
<td>CD-R – up to 700 MB DVD-R – 4.7 or 9.4 GB Blue Ray and UDO – 50 and 60 GB Holographic – in development, approaching 600 GB</td>
<td>Up to 1 TB</td>
</tr>
<tr>
<td>Life expectancy</td>
<td>Technology Obsolescence (TO) is determining factor</td>
<td>TO and varies by types of media and method of handling</td>
<td>TO and varies by types of media and method of handling</td>
</tr>
<tr>
<td>Reliability of media</td>
<td>Excellent, but subject to corruption</td>
<td>Excellent, but subject to improper handling and labeling errors</td>
<td>Varies depending on type of tape and maintenance, data corruption occurs</td>
</tr>
<tr>
<td>Human intervention required</td>
<td>Minimal to none</td>
<td>Some, depending on type of optical disk and juke box</td>
<td>Some, depending on type of tape, tape drive, and juke box</td>
</tr>
<tr>
<td>Relative cost</td>
<td>Must be evaluated on a case by case basis – storage media represents about 5–10% of the total storage management cost</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 14.6.2 Storage Management Infrastructure and Hardware

- As the quantity of digital information grows in the healthcare environment, the requirement for a secure, highly available, and cost-effective storage management solution becomes imperative. Backup and DR are also dependent on the storage management solution selected. Factors to consider in this selection process include:
  - **Capacity** – amount and type of data (file level or block level) to be stored or shared
- Performance or availability – input/output and throughput requirements
- Scalability – long-term data growth
- Availability and reliability – how mission-critical is the application
- Data protection – backup and recovery requirements
- IT staff resources and capability
- Initial and annual budgetary availability

- **Direct attached storage (DAS)**
  - Simplest and least expensive storage technology where computer (server) is directly attached to storage device such as RAID or tape system.
  - Workstations must access server to connect with storage system.
  - Since the server must handle processing for the application(s) as well as servicing the storage device, availability of stored data is impacted and thus system performance, e.g., queries for clinical studies are compromised.
  - Other disadvantages of DAS are scalability and the ability to automate backup and minimize planned system downtime.

- **Network attached storage (NAS)**
  - Developed to address the inherent weaknesses of a server-based infrastructure such as DAS.
  - NAS is a **file-based** storage system with management software that is 100% dedicated to serving files over a network.
  - NAS eliminates the need for the server **supporting** storage and responding to read/write responsibilities.
  - Uses industry standard IP network technology and protocols (Transmission Control Protocol/Internet Protocol [TCP/IP], Common Internet File System [CIFS] and [NFS]).
  - NAS can provide
    - Simple and cost-effective ways to achieve fast data access for multiple clients at the file level.
    - Achieve performance and productivity gains over DAS.
    - Data protection features such as replication and mirroring for business continuance.
    - Ability to consolidate DAS resources for better utilization.
    - Scalability with storage capacity in the multi-terabyte range with efficient use of datacenter space.

- **Storage area network (SAN).**
- A SAN is a dedicated, high-performance storage network that transfers data between servers and storage devices, separate from the local area network.
- SAN moves data at the block level rather than at the file level as does DAS and NAS, thus it is ideal when large quantities of data must be moved.
  - Since the SAN operates on a block level and workstations operate at the file level, the PACS or other application must provide a block level to file level conversion.
- A SAN environment is more costly, complex to manage, has many components, and requires sophisticated management software than other storage management environments; however, it provides superior
  - Performance
  - 24 × 7 data availability
  - Reliability, i.e., high degree of fault tolerance
  - Scalability
  - Data protection
  - Storage virtualization
- In a SAN infrastructure, storage devices such as DAS, NAS, RAID arrays, or tape libraries are connected to servers using fibre channel.
- Since a SAN provides a high-speed connections between a storage device and a server:
  - The server can respond to the computations required by the applications without supporting the storage system.
  - Copies of the server’s operating system and applications can reside on the storage systems supported by the SAN and can be rapidly restored should they fail.
- Currently, less costly and easier to manage SANs are available costing significantly less than $100,000.

- Fibre channel (FC)
  - FC is a gigabit-speed network technology used primarily for storage networking.
  - FC uses special cabling to move large volumes of data without the distance and bandwidth limitations of SCSI.
  - FC has transmission rates of 1, 2, 4, 8, 10, and 20 Gbps.
  - FC is highly reliable and enables simultaneous communication between workstations, mainframes, servers, data storage systems, and other peripherals.

- Hybrid SAN/NAS
  - Adds file interface to SAN
  - Supports NAS standards
  - Leverages a common storage infrastructure
- Internet Small Computer System Interface (iSCSI) Storage system
  - iSCSI uses IP networks rather than fibre channel to transmit data.
  - Unlike FC that requires special-purpose cabling and is more expensive, iSCSI can run existing, less expensive network infrastructure.
  - iSCSI enables data storage and retrieval from remote and independent storage systems because IP networks such as LANs, WANs, and the Internet are widely available.
  - iSCSI has transmission rates of 1 Gbps and 10 GBps but require more overhead than FC.

### 14.6.3 Storage Management Software

- Data protection software
  - Backup
    - Used for VCF such as RIS or demographic database
    - Make daily manual backup to tape and stored in a secure remote off-site location
    - Various automate backup methods available; however, secure off-site copy must have
      - Replication
      - Point-in-time (PIT) copies
      - Continuous data protection
  - Archiving
    - Used for FCF such as patient studies.
    - Can be automated using hierarchical storage management (HSM) application, grid storage or clinical information lifecycle management application (CILM).
    - Can be performed manually by copying studies acquired each day to tape or other removable media and stored in a secure remote off-site location.
  - Grid storage
    - Software application used to manage Tier 2 and Tier 3 storage of FCF at multiple geographically separated locations.
    - Each location may have one or more nodes of the grid software operating on off-the-shelf hardware that manages a storage resource.
    - Nodes are interconnected via network links and can process DICOM store and query requests from any node.

Further Reading 14.17: Grid Software

- www.bycast.com
• Grid provides a scalable fault tolerant and redundant application that does not have a single point of failure.
• The healthcare institution must have or have access to multiple geographicaly separated storage locations for grid storage to be applicable to take advantage of its many attributes.

• **Storage virtualization.**
  - Can be a hardware or software or combined hardware and software solution available from many vendors that facilitates pooling of storage resources.
  - By pooling storage resources they can be organized, allocated, and managed without regard for their physical location optimizing the efficient use of an institution storage resources.

• **Administrative software should consist of**
  - Proactive monitoring and automated fault detection 24/7 – optimally should be provided by the storage vendor. If the application vendor sold the storage solution, it is advisable to have the OEM provide this service.
  - Integrity checks should be performed on all stored data to detect errors (data corruption), media degradation, and tampering.
  - Providing audit logs of access to all stored data.
  - Providing status of available storage resources.

• **Hierarchical storage management (HSM)**
  - Used to manage movement of FCF from one tier of storage to another based on
    • Time and date stamp on file
    • File size
    • Activity of file, when was the last time it was accessed
  - Does not use metadata in DICOM header to manage file such as demographic, procedure, or modality information.

• **Clinical information lifecycle management (CILM)**
  - CILM is based on policies established and business value of the information with the most appropriate and cost-effective IT components from the time the information is conceived to final disposition.
  - Studies with the maximum business value are maintained on storage resources that the study can be rapidly retrieved and as the business value decreases, it is migrated to less expensive storage resources, e.g., initially on Tier 1 fast disk to Tier 3 MAID or tape storage.
  - The policies are established from information in the
    • File header as would HSM
    • DICOM header of image file
- Departmental information systems such as RIS, CIS, etc.
- Enterprise information systems, e.g., HIS

Examples of how CILM could be used
- Patient study is normal – maintain on Tier 1 storage for 3 months and on Tier 2 and 3 as mandated.
- Patient has normal mammogram – maintain on Tier 1 storage for 15 months and on Tier 2 and 3 as mandated.
- Patient study indicates tumor – maintain on Tier 1 for 15 months after tumor has been removed or regressed and on Tier 2 and 3 until 2 years after patient is deceased.

14.7 Compression of Medical Images

14.7.1 Reasons for Compressing FCF

- Decrease transmission times for medical images
- Decrease storage requirements for medical images
- Decrease bandwidth requirements for the transmission of medical images
- Reduce cost for storage management and infrastructure

Key Concepts 14.18: Image Compression

1. The primary justification for compressing FCF DICOM objects is reducing the time to transmit an image from one location to another that directly affects productivity and reduces storage requirements and cost.
2. Studies interpreted based on a lossless compressed image MUST be stored in lossless compressed format.
3. Studies interpreted based on a lossy compressed image MUST be stored using the same lossy compression algorithm.
4. All medical images must be stored in either a lossless or lossy DICOM compliant compression format.
5. Proprietary compression formats.

- Will negatively impact interoperability of images and data migration
- Can lock you into your current PACS vendor


14.7.2 Lossless Compression

- Run length encoding (RLE)
  - Uses the redundancy within the image to decrease the image size
  - Replaces sequences of the same data values within a file by a count number and a single value
  - Reduces image size between 1.8 and 2.8 depending on modality and body part

14.7.3 Lossy Compression

- Primarily used for web distribution of images to the enterprise for review purposes rather than primary interpretation.
- Lossy compression ratios must be stated on each image of a study.
- Study can be restored with no significant loss of clinical data.
- Lossy compression ratios depend on body part and modality.
- Typical compression ratios used when interpreting lossy compressed images.
  - DR and CR – 20 to 1
  - CT – 10 to 1
  - MR – 5 to 1
- Based on a study sponsored by the Canadian Assoc. of Radiologist by Dr. David Koff to evaluate JPEG and JPEG-2000, lossy compression found that it had no effect on diagnostic accuracy for all modalities and body parts tested.
- The wide-spread use of lossy compressed for primary interpretation of studies will have a significant impact on cost of infrastructure and storage management.
14.8 Disaster Recovery (DR) and Business Continuance (BC)

14.8.1 General

- DR is mandatory, but not sufficient to provide the level of availability of ePHI required in a healthcare environment. BC must also be implemented to provide a satisfactory level of availability.
- DR of medical information is part of the total DR program.
  - HIPAA security regulation requires backup/DR of “retrievable exact copies of ePHI”
- DR required due to
  - Component failure – high probability
    - Server, storage system, or media
    - Data corruption
    - Human error
    - Virus, internal, or external system breach
  - Catastrophic event – low probability
    - Major power failure due to severe ice or snow storms
    - Fire, flood, hurricane, tornado, earthquake, etc.
    - Terrorist act
- DR will provide the means to restore or recover ePHI lost as a result of component failure or from a catastrophic event.
- BC will provide the availability to access the ePHI until the systems and ePHI are fully restored to the normal operating conditions.

14.8.2 Options for DR

- Backup information on tape or other media and store securely
  - Off-site in a fire and heat-proof safe.
  - With a secure storage vendor.
  - They satisfy the letter of HIPAA, but will not minimize downtime.
  - They do not satisfy the spirit of HIPAA, but they are the least expensive, but also expose the healthcare facility to significant risks.
- Backup information in a second secure datacenter operated by healthcare facility preferably at a site 100-plus miles from the primary site.
  - Satisfies both the letter and spirit of HIPAA and can help minimize downtime.
- Rent space and functionality at a Tier 3 or Tier 4 datacenter located at least 100-plus miles from the healthcare facility.
– Acceptable, but expensive since hardware and software must be purchased and datacenter services must be leased.

- Store data in multiple datacenters owned by healthcare facility and utilize grid storage technology (applicable for FCF only).
- Satisfies both the letter and spirit of HIPAA and can help minimize downtime.

- Out-source the management and storage of DR and possible long-term storage (Tier 2) as well as BC to a storage service provider (SSP).
- Can be the most cost-effective solution and minimizes the use of physical and personnel resources of a healthcare facility.

Further Reading 14.23: Options for Disaster Recovery


14.8.3 Fundamentals of BC

- Some of the basic requirements for a BC plan are
  - Practice and document workarounds for system components that may fail, as examples:
    - Hard-wire at least one of each critical modality to a DICOM compliant laser printer should the infrastructure fail.
    - Should the demographic database become unavailable or prior studies are not available on Tier 1 or Tier 2 storage arrange to retrieve the necessary studies from Tier 3 storage using a general purpose viewer.
    - Download all necessary studies to a computer in the surgical suite if they are essential for a surgical procedure prior to starting the procedure.
  - Eliminate single points of failure (SPOF) in the infrastructure including routers, switches, application gateways, and interfaces, etc.
  - Alternate data pathways should a transmission line be accidentally cut.
  - Alternate backup power sources including both uninterruptible power sources that must be checked weekly and automated emergency power generation capability.
  - A test server must be used to test all application and upgrades as well as new applications prior to clinical use.
If economically feasible and information technology support is available, servers should be clustered or virtualized and DAS eliminated in favor of more robust storage solutions.

- **Planned versus unplanned downtime**
  - Planned downtime should be held to a minimum and scheduled to have minimal impact on clinical operations.
  - Workarounds should be developed for planned downtimes.
  - Vendors requiring planned downtimes to re-index or synchronize databases and similar activities should be frowned upon.

- **Require all vendors providing hardware or software components to the digital healthcare environment to provide a Service Level Agreement (SLA) that is enforceable and contains MONETARY penalties if they do not adhere to the commitments in the SLA.**
  - Planned downtime is excluded from the SLA.
  - The penalties associated with the SLA should be increased for each time the vendor fails to meet the SLA.
  - The period over which the downtime is calculated for the SLA must be clearly specified as illustrated in the following table. Obviously downtime for the life of the contract is most favorable for the vendor and downtime per event is most favorable for the healthcare institution (Table 14.8).

<table>
<thead>
<tr>
<th>SLA</th>
<th>Downtime per life of contract</th>
<th>Downtime per year</th>
<th>Downtime per month</th>
<th>Downtime per event</th>
</tr>
</thead>
<tbody>
<tr>
<td>99.0%</td>
<td>87.6 hours</td>
<td>87.6 hours</td>
<td>87.6 hours</td>
<td>87.6 hours</td>
</tr>
<tr>
<td>99.9%</td>
<td>8.76 hours</td>
<td>8.76 hours</td>
<td>8.76 hours</td>
<td>8.76 hours</td>
</tr>
<tr>
<td>99.95%</td>
<td>4.38 hours</td>
<td>4.38 hours</td>
<td>4.38 hours</td>
<td>4.38 hours</td>
</tr>
<tr>
<td>99.99%</td>
<td>52.6 minutes</td>
<td>52.6 minutes</td>
<td>52.6 minutes</td>
<td>52.6 minutes</td>
</tr>
<tr>
<td>99.995%</td>
<td>26.3 minutes</td>
<td>26.3 minutes</td>
<td>26.3 minutes</td>
<td>26.3 minutes</td>
</tr>
</tbody>
</table>

### 14.8.4 Backup and DR for VCF

- Entries to VCF such as the database of the radiology information system (RIS) are made continuously, as compared to FCF such as a clinical study that has been interpreted and signed.

- At a minimum, VCF must be backed up daily and preferably multiple times during the day depending on the frequencies of new entries, “writes or changes” to the database.
  - If a database is corrupted all of the entries since the most recent backup will have to be re-entered after the database is restored from
the most recent backup or point-in-time replication. This can be both time consuming and costly at best, especially as an institution becomes paperless.

- At many institutions, databases are backed up to magnetic tape; however, magnetic disk is faster, minimizes or eliminates downtime, increases data integrity, and may decrease cost in the long run **if** the backup is transmitted to a secure datacenter or out-sourced to an SSP.

- There are several protocols for backup and DR of VCF:
  - The least desirable approach is to make a backup on tape each night while the system is not clinically operational, label it, and take that copy to a secure off-site location. Three copies of the backup would always be retained and rotated:
    - Current day’s backup would be dated and labeled daughter copy,
    - Previous day’s copy labeled mother copy, and
    - The prior day’s copy to the mother copy, labeled grandmother copy.
  - If disk is to be used as the backup medium, typically the database would be stored on a SAN and a complete backup would be made each week and a backup of all changes to the database would be made each day. Copies of the backup would be transmitted daily off-site to a secure datacenter or SSP.
  - For databases having large volume of daily transactions or for an institution that is approaching a paperless environment, periodic backups (replications or point-in-time) during the day (asynchronous) or real-time backups (synchronous) would be preferable. This would be in addition to the disk backup protocol described above.

- Daily and weekly copies of the database MUST be kept off-site in a secure and accessible location.

- A copy of the database should be **restored on a test server** to ensure its integrity at intervals established by the healthcare facility. Do not restore a backup or DR copy of a database on a clinical server until its integrity is determined. If the database is corrupted, it will disrupt clinical operations.

### 14.8.5 Backup and DR for FCF

- After studies (FCF) are forwarded to Tier 1 storage and in some cases to specified workstations for emergent studies, they should be
  - Validated if modality worklist (MWL) has not been implemented and
  - Preferably the radiological interpretation has been signed prior to forwarding the study to Tier 2 storage, if accomplished within a reasonable
period of time after the study has been completed to ensure that two copies of the study are always available.
- These steps will minimize having to alter or attach overlays, annotations, etc., to studies located in multiple storage locations.
- All studies not forwarded to Tier 2 storage by the end of the regular clinical day should be forwarded as soon as possible.
- At the end of the clinical day studies should be encrypted and backed up to Tier 3 storage, i.e., DR, at an off-site location or to a storage service provider.
- All access to DR copies of studies should be audited and periodically the integrity of these studies should be verified.

14.8.6 Justifying the Cost of DR and BC

- As the healthcare facilities information environment becomes completely digital, the availability of paper- and film-based information approaches zero, the availability of the digital environment must approach 100%.
- The question becomes, how much downtime and on which systems can the healthcare tolerate, considering the impact on
  - Patient care
  - Productivity
  - Finances – lost revenue, continuing expenses, and cash-flow
  - Adverse public relations – patents, staff and referring physicians, and general public
- Mandatory procedures and additional precautions to provide DR and an acceptable level of BC will add to the operating cost of the digital environment
- Calculate the cost of DR and BC to maintain the required availability of ePHI versus the tangible and intangible cost of downtime.
- Can a healthcare facility not justify paying for “downtime insurance”? It is a form of “risk management insurance” similar to other insurance policies carried.

14.9 Migration of Medical Images and Related Data

14.9.1 Reasons for Migrating Data

- Purchasing a new PACS.
- Upgrading the existing PACS.
• Converting from silos of departmental storage to an enterprise storage system.
• Upgrading or technological obsolescence of storage components.
  – Storage components typically have a three-year warranty period after which the typical maintenance fee is 15% or more per year.

14.9.2 Factors that Impact Data Migration

• RIS and modalities must support DICOM modality worklist (MWL) if not, up to 20% of studies may have errors in the DICOM header that will negatively impact data migration.
• HIS or RIS upgrades during the operation of existing PACS, may create incompatibilities in certain fields in the DICOM header and the demographic database during data migration.
• Compatibility of data requirements between new and existing PACS vendor, e.g., missing or accuracy of data in DICOM fields.
• Existing PACS vendor stores data in proprietary format.

14.9.3 Data that Must be Migrated for a PACS

• Demographic database that contains the records and pointers that will allow the new system to perform a query/retrieve and know what studies are available. There will probably be problems in converting the database, e.g.
  – Different name representation, e.g., John Edwards and John E. Edwards
  – Two MRNS for the same patient
  – Missing accession numbers
  – Unverified studies
  – Missing DICOM header information
• Studies that are “hopefully” in a nonproprietary DICOM compliant format
• Related information such as key images, overlays, annotations, and other information that is used by the person viewing the studies

Further Reading 14.25: Data Migration

14.9.4 **Who Will Migrate Data?**

- Use institution’s IT personnel.
  - Will divert personnel resources from regular responsibilities.
  - Possible option if existing archive is relatively new, there is minimal data cleansing and the volume of data is manageable.
  - Verify that using nonvendor personnel does not invalidate product’s warranty.
- Always obtain and verify references from vendor of previous data migration engagements that have similar clinical and data environment.
  - Current PACS vendor has very little incentive to perform effective data migration with respect to accuracy, speed, and cost.
  - Future PACS vendor has an incentive to please client and perform an effective data migration with respect to accuracy, speed, and cost.
    - Vendor may combine cost for data migration and new PACS making it difficult to determine actual cost of data migration.
    - Finger pointing may occur between old and new PACS vendors.
  - Vendor that specializes in migrating DICOM objects – they represent a neutral party and have the greatest experience in data migration.

14.9.5 **Impact on Clinical Operations**

- Data migration requires access to the same database and storage system that the existing PACS needs to access and may slow down clinical applications.
- In most situations, data migration will occur in the evening and weekends or at times when PACS utilization is at a minimum.
- Prior studies should be available in the new archive, prior to its active use, if not users will have to retrieve prior studies from the old PACS/storage system and current studies from the new system – this can negatively impact productivity. When to start migration must be determined and is dependent on the type of institution and patient population.

14.9.6 **Economics of Data Migration**

- Administration unaware and unwilling to pay the significant cost. Make administration aware of this cost:
  - When purchasing PACS and how cost can be minimized with “pre-nuptial” agreement when acquiring new PACS and requiring vendor to maintain data in DICOM compliant format, etc.
Hardware and software components, especially storage management components will be technically obsolete in 3–6 years depending on when purchased in their life-cycle.

- The cost of data migration is highly dependent on:
  - Whether or not the data to be migrated have to be cleansed with respect to DICOM header and database.
  - Whether or not the data are in non-proprietary format.
  - The method used to migrate the data.
  - Cooperation of both new and old vendor.

- The existing PACS vendor may charge a fee to facilitate data migration.

- Depending on the amount and condition of data, the vendors involved the cost to migrate data is variable, e.g., for one institution the cost to migrate 12 TB of data including minimal data cleansing cost just over $200,000 after considerable negotiations and took approximately 6 months to complete.

- Since data migration, depending on the amount of data to be migrated, can take 12 months or longer, the cost of maintaining the old PACS must be considered.

### 14.9.7 Mitigating Future Data Migration Problems

- Require a “pre-nuptial” agreement from the PACS vendor regarding data migration including cost of migrating both the data and the database as part of purchase contract.

- Implement an enterprise storage system requiring all PACS vendors to forward all studies in a DICOM compliant format to a third-party DICOM compliant archive.

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**Our Experience 14.26: Data Migration**

Existing PACS vendor charged a licensing fee to allow data to be moved to third-party archive and a per TB fee for the data actually moved. These fees were partially justified in the author’s opinion, but were excessive.

**Further Reading 14.27: Data Migration**

Pearls 14.28

- Eliminate isolated silos of storage and implement an enterprise storage solution.
- There are various storage media types and storage architecture to select from:
  - For individual patient studies – medical grade CD-R or DVD-R.
  - For database storage (VCF) RAID 1 or RAID 10 using 10,000 or greater RPM disks with storage capacity up to 250 GB.
  - For database backup (VCF) on-site on a SAN and at an off-site location on disk or less desirable magnetic tape.
  - For Tier 1 FCF RAID 5 or preferably RAID 6 using 7,500 or greater RPM disks with storage capacity up to 500 GB with sufficient storage for 3–18 months of studies.
  - For Tier 2 FCF RAID 5 or preferably RAID 6 using 5,000 or greater RPM disks with storage capacity up to 1 TB with storage capacity for the legal life of the studies.
  - For Tier 3 (DR), FCF located at a datacenter 100 miles or more from the institutions primary data center or outsourced to a storage service provider. Preferably storage media should be disk in either an RAID 5 or 6 format or MAID format, alternatively, but less desirable, magnetic tape or least desirable DVD-R.

- A study interpreted from a restored lossless compressed format must be stored/archived in that format; likewise, a study interpreted from a restored lossy compressed format must be stored/archived in that format.
- Disaster recovery is necessary and mandated by HIPAA to restore ePHI after a component failure or catastrophic event, but recovery of ePHI will take a finite period of time. Business continuance is required to maintain the availability of ePHI during the period of recovery. The combined cost of DR and BC is significant and should be considered as hazard insurance, part of an institution’s risk management program.
- PACS vendor must guarantee in writing that all stored FCF DICOM objects are stored in a DICOM compliant format that can be copied to a third-party DICOM compliant archive with no vendor intervention and no additional cost.

Self-Assessment Questions

1. Which of the following is an advantage of departmental storage over enterprise storage?
   a. vendor independence and best-of-breed purchasing
   b. reduced cost of hardware and licensing fees
c. ease of providing redundancy
   d. None of the above

2. Which of the following is true about the economics of storage management?
   a. Once storage is purchased, it is no longer an ongoing annual budget item
   b. Media itself accounts for approximately 50% of the total cost of storage
   c. Storage costs include personnel, utilities, datacenter space, and data backup
   d. Technological obsolescence will require upgrades approximately every 10 years.

3. Regarding datacenters, which of the following is true?
   a. Tier 4 is the highest Tier rating for datacenters.
   b. The IT Department is responsible for specifying the characteristics of the resources and the availability requirements.
   c. Power and cooling represent a small cost fraction of datacenter costs
   d. 24/7 information availability is desirable, but not necessary.

4. The retention period for PHI depends on all of the following EXCEPT:
   a. age of patient
   b. gender of patient
   c. federal statues
   d. state statutes

5. Which of the following must be documented when destroying PHI?
   a. Method of destruction
   b. Inclusive dates covered
   c. Statement that the records were destroyed in the normal course of business
   d. All of the above

6. Which of the following is an example of optical media?
   a. DVD
   b. Hard drive
   c. Tape drive
   d. Flash drive

7. Which of the following is NOT a form of network storage?
   a. RAID
   b. SAN
   c. NAS
   d. WAN
8. Evaluating the value of information over time to find the most cost-effective means of storage and disposition is called
   a. HSM  
   b. CILM  
   c. MAID  
   d. PIT

9. Imagine that you are planning a massive data migration in a busy department when changing PACS vendor. Which data would you move first? At what days and times would you perform the migration?
   a. the most recent prior studies and build a new demographic database  
   b. the oldest prior studies and build a new demographic database  
   c. 24 hours × 7 days per week since there is much data to migrate  
   d. during periods when there would be minimum impact on clinical activities

10. Which of the following methods is the most desirable DR method for the RIS database?
    a. multiple copies at multiple locations on the enterprise storage solutions SAN  
    b. daily and weekly copies off-site on FCF Tier 3 storage  
    c. multiple copies made at several intervals during the day on the enterprise SAN and a daily copy sent to an SSP  
    d. daily and weekly tape copies sent off-site daily to a secure storage facility

11. Which RAID level will provide the best performance, redundancy, and availability for a busy Radiology Department’s RIS database?
    a. RAID 1  
    b. RAID 5  
    c. RAID 6  
    d. RAID 10
Chapter 15
Downtime Procedures and Departmental Policies

Claudine Martin

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15.1 Introduction

A critical component of clinical operations in today’s electronic world is digital healthcare information and management system (DHIMS) and picture archival and communication system (PACS) networks. While medical images are used in all clinical areas, some specialties like emergency medicine and surgery rely heavily on the availability of these data. Medical management of a patient can either stop or be put on hold if images are not available. Additionally, printing film may not be an option for facilities due to reduction of all resources associated with the printing and handling of film.

Proper management is required for any organization that depends on technology. A well-defined set of policies and procedures along with other key management components such as a reliable primary system and backup architecture for redundancy should be in place to ensure patient safety and minimize operational inefficiencies.

15.2 Downtime Considerations and Types

Downtime procedures are an important component of the overall policies and procedures of PACS. Additionally, these procedures must account for the fact that a downtime can be either unscheduled or scheduled. Disaster recovery procedures may be enacted in the event of a major system outage caused by
flood, fire, or other catastrophic event. Downtime typically lasts from 5 minutes to 8 hours, with an average of about 1 hour. While an hour may not seem like a lengthy amount of time, it is an unacceptable delay when patients are involved.

- **Planned downtime** (e.g., patch installation or software upgrades) can be scheduled at the least disruptive time of the day since you can decide when the downtime will occur.
  - Be sure to understand the vendor’s downtime requirements for upgrades as well as maintenance since vendors may require multiple hours of downtime.
  - Consider times where you will still have a “buffer” of time in case a downtime is longer than expected.
  - You may want to consider upgrading less frequently to avoid disruptions, and only when there are features or bug fixes in the upgrade that are important to your institution.
  - A “roll-back” plan should be in place in the event that a new release introduces problems that are not acceptable for your facility.

- **Unplanned downtime** (e.g., an unexpected system failure) can be avoided by informed decision making when buying, installing, or configuring a system. As well, unplanned downtime can be minimized by investing in infrastructure for business continuance.
  - Try to find reference sites similar to yours, with similar information technology products, and gather information about downtime experienced at the reference site.
  - Remember that if you are one of the first sites to get this product or upgrade, there will be little or no information available to you.
  - An assessment of your information technology products and infrastructure should be made to identify every single point of failure with the qualification that the more critical the function, the higher the priority must be to create redundancy.

**Key Concept 15.1:**
**Information Technology Products and Infrastructure**

All products and systems that could cause or could be affected by an unplanned downtime. Examples include information systems, network switches, Internet, etc.

**Definition 15.2:**
**Single Point of Failure**

If failure of a single piece of software or hardware can cause the entire system to stop functioning, this is a single point of failure. Single points of failure are dangerous, and are combated with redundancy.
15.3 Policies and Procedures

Downtime policies and procedure are often specific to each facility’s departments and provisions, but basic procedures such as the following should be in place at every institution.

- **Modality downtime procedures** – procedures to identify how to continue operations when the worklist is unavailable and when the ability to send to the PACS is compromised (either slow transmission or failed transmission). PACS data integrity can be impacted when manual data entry is required during a downtime. Additionally, image availability may become an issue if there is no procedure in place to ensure transmission of all acquired data after the downtime has ended. **Postdowntime procedures** should include a check that all data acquired during the downtime have been successfully sent to PACS and of the sent data, corrections should be made to any exams that have patient demographics errors due to manual data entry.

- **Infrastructure downtime procedures** – procedures to identify how to continue operations during electrical, HVAC, network, or information system (EMR/HIS) outages.
In the event that the primary PACS is affected by an electrical, HVAC or network issue, a procedure should be in place to transition to the **back-up PACS** (which should be physical location that does not rely on the same infrastructure as the primary PACS).

Downtime of the HIS may require procedures to **manually enter patient demographics** in order to continue to acquire new exams.

- **PACS downtime procedures** – a comprehensive policy to cover all possible systems and scenarios associated with PACS (PACS, diagnostic workstations, HIS/RIS, Dictation system, modality, etc.). Procedures such as
  - Workstation back-up and recovery and associated tools such as Norton Ghost, etc
  - Video card replacement and configuration
  - Transition to transcription services if speech recognition is unavailable

- **User notification**
  - Scheduled downtime: includes all variations of user notification. Different departments will require different notification channels, depending on criticality of notification. Even if enterprise notification can be achieved by displaying a notification in the most widely used systems such as the HIS/EMR, additional notification should be considered for locations such as emergency medicine, surgery, etc. This may be delivered by a direct phone call to location or a page to specific distribution lists. Along with the notification, information should be provided regarding how images and results will be provided during the downtime.
  - Unscheduled downtime: outline how to report the downtime to both internal and external stakeholders (such as how the downtime should be communicated to the associated vendor), the steps to be taken during the downtime, and the **escalation policy** throughout the duration of the downtime.

- **Disaster recovery** procedures – procedures to outline data restoration procedures for database server(s), image server(s), etc. While the actually steps might be performed by the vendor, information should be available regarding what is expected of internal staff.

- **Incident report** – should contain information such as clinical and business impact, duration of outage, step taken to restore service, and postdowntime root cause ana-

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**Definition 15.4: Escalation Policy**

The first point of contact (either the vendor’s or yours!) may not respond in a timely fashion. Who do you contact next? Who do you contact if that person fails to respond? This sequence of individuals is an escalation policy.

**Definition 15.5: Incident Report**

Post downtime report provided by the vendor explaining the cause of any unscheduled downtime.
lysis. It is important to agree on when an outage “technically” starts as you might think it is a first loss of service while the vendor might think it is at the time it is reported to them. The duration will determine whether the “uptime guarantee” was met by the vendor.

Further Reading 15.6: PACS Operational Policies and Procedures

The Society for Imaging Informatics in Medicine (SIIM) has presentations given over the previous years on some of the key topics discussed in this chapter. For example, as part of SIIM 2007 SIIM University Sessions, a PACS Operational Policies and Procedures section is available online at http://www.siimweb.org/presentations.

15.4 Minimizing Downtime

15.4.1 Planning at Multiple Levels

Planning involves both operational and technical aspects. Through comprehensive planning, PACS users can maintain a similar level of service during scheduled downtime and also minimize the effects of an unscheduled downtime.

While procedures should be developed to handle both scheduled and unscheduled downtime, well-defined decision criteria should be in place for when to switch to backup operations. Remember that changing personnel tasks and possibly applications and/or systems at the start of a downtime may take longer than the actual downtime. An estimate of the downtime from the vendor should be made and decisions should be made based on that information. Often times, it might be better to wait out the outage than to begin the transition strategy to the back-up PACS.

As for communications, consider the following:

- For scheduled downtimes, frequent communications should be made to house staff, referring physicians, vendors, etc., well before the scheduled downtime. This communication should include what the downtime will mean to them and their ability to do their jobs and not just the duration of the downtime.
- For unscheduled downtime, keep users informed of what is happening and provide an estimate of the duration of the continued downtime. If users are informed, they will not keep calling the support team and distracting those who may be working on the problem.
- For both scheduled and unscheduled downtimes, a single point of communication such as a service desk or radiology front desk should be considered to ensure the appropriate people are handling the communication to end users.
- Electronic notifications through the paging systems, EMR and departmental web sites, and digital dashboard are all channels to get the downtime information to all end users, especially during unscheduled outages where the downtime needs to be communicated quickly.
- Departmental web site should contain links to all downtime procedures.

1. **Technical**
   The following technical solutions should be considered to minimize the effects of a downtime:
   - PACS vendors will generally recommend a **full data backup** before any upgrades because there is always the risk of losing data. Have the vendor perform a full backup before the downtime starts so that the duration of the downtime is not extended.
   - Maintain **multiple workstations** to minimize inefficiencies in the event of a major hardware failure of a primary workstation. Also, consider maintaining some parts of the workstation (e.g., monitor, mouse) as spares in case a workstation has an equipment failure in a location where a user cannot leave like the operating room.
   - Make available a **web-based viewer** to run on a PACS workstation. This viewer could be used against the back-up PACS as a ready-viewing option rather than having to change the configuration of the thick-client PACS application (quite possibly at every workstation).
   - Utilize a **backup PACS**. It is important to know how much data can be stored on the backup to ensure availability of exams for prior comparison and elective surgeries. Additionally, one should know the mechanism by which images are sent to the backup PACS. If the images are forwarded from the primary PACS, then images acquired during the downtime of the primary PACS may not reach the backup PACS. It is important to know whether the backup PACS can support other operations like dictation; otherwise, **paper-based information** tracking may be necessary.
   - Consider a Digital Imaging and Communications in Medicine (DICOM) **router** to send images to multiple destinations like the primary and backup PACS along with other systems like an advanced visualization system that can be used for primary reading during a downtime.
   - Lastly, consider a **fault-tolerant PACS** in which no part of the system has a single point of failure.

2. **Operational**
   The following operational solutions should be considered to minimize the effects of a downtime:
• Schedule the downtime at the **least disruptive time** such as over a weekend and also with enough days notice so that radiology schedulers can adjust accordingly.
• **Increase staffing** prior to the start of the downtime to reduce the number of unread studies and after the downtime to reduce the workload of individual radiologists.

**Our Experience 15.8: Utilization of Backup PACS**

While at the University of Pittsburgh Medical Center, we developed a solution for what is now called our Business Continuity Servers (BCS) or what is referred to in this chapter as a Backup PACS. Initially, we started out with a single server that could be fed image data from the modality directly during a downtime. This was operationally complicated since technologists were expected to change “send” destinations on the fly.

Our next initiative was to have the modality send to a single destination of a DICOM router. Thus, the routing could be changed at only one (or a handful) of DICOM routers rather than the dozens of modalities and by a staff person who was not expected to be doing other tasks, as well, like imaging patients.

Upon having the DICOM router in place, it became obvious that sending from one of the remote facilities within the medical center to a centrally located BCS put a significant strain on the Wide Area Network (WAN) which, in turn, impacted transmission of image data to the BCS. Our solution was to implement a BCS at each PACS location within UPMC.

While this solution worked well for newly acquired data, the BCSs had a limited amount of storage that depended upon the volume of each PACS site. While the BCSs could ensure that images from the emergency department could be displayed, there could be no guarantee of image availability for routine, but critical times such as during surgery. To improve upon our solution, we worked with our PACS vendor to scale the BCS storage to ensure that the last 6 months of image data would always be available for display.

**Key Lessons Learned**

• Do not wait for the perfect solution before implementing. Have something in place and improve upon it with feedback from each downtime event.
• Have procedures in place to transition from primary PACS to backup PACS that includes operational, technical, and communications.
• Work with your PACS vendor for a backup PACS, but be careful to know how image data will get to the backup. If it has to be processed through the primary system, the data may not arrive to the backup during a downtime.
- Develop procedures to reduce the potential for data integrity issues such as in the event that worklist is unavailable, how to manually enter patient demographics into the modality. Also, in the event of DICOM send failures, how to locate exams being held on the modality and manually send them to PACS upon resumption of service.

15.4.2 Business Continuance and Disaster Recovery

To minimize downtime, a plan is needed for business continuance and disaster recovery. Your budget will be an issue when considering your institution's fault tolerance (how much are you willing to operate in a compromised operational state). At a minimum, serious consideration should be given to redundant systems for your institution's major applications (such as RIS and PACS). The impact, both operationally and clinically, of extended downtime on such critical systems will likely justify this investment.

The idea behind business continuance is to eliminate any single point of failure so that in an instance of a failure of any one function, an identical secondary function is immediately available to reduce disruption in service. For example, a PACS may have a single database running on a central server. Additionally, all client workstations interact with that central server in order to run the PACS software. In the event of a downtime, because the server controls multiple workstations, the impact on your operations is much more significant. A second server and database can be “clustered” with the first server allowing for the servers to be synchronized. In the event of a database failure on one of the nodes of the cluster, the system will automatically fail over to the other node of the cluster and resume service.

As mentioned previously, an assessment of your information technology products and infrastructure should be made to identify every single point of failure with the qualification that the more critical the function, the higher the priority must be to create redundancy.

Disaster recovery is another important element when using a PACS. A single copy of image data on a single server in only one location is an obvious risk. Additionally, modalities no longer archive images to disc so after roughly a week of being stored on the modality, the images are no longer available at the modality. Without disaster recovery procedures in place, your institution could suffer data loss in the event of a disaster. Luckily, with the availability of secure networks to external locations, a second copy of data can be transported to a data center in a separate location.
**Pearls 15.9**

- Inevitably, systems will fail and the hospital should include a PACS downtime contingency plan in its strategic plan. The contingency plan should include emergency resource contacts, an overview of the goals of the plan, and procedures and policies for all types of downtime.
- Through comprehensive planning, institutions can maintain a similar level of service during scheduled downtime and also minimize the effects of an unscheduled downtime.
- Successful development of policies and procedure is an ongoing effort. Periodic reviews and updates should be performed to reflect changes in PACS technology and in clinical operations.
- Business continuity is all about keeping systems functioning despite a major failure, while disaster recovery deals with recovering after a catastrophic failure.

**Suggested Reading**


**Self-Assessment Questions**

1. Which of the following is NOT a downtime type?
   a. Hardware failure
   b. Network
   c. Printer failure
   d. Software failure
   e. Electrical

2. Which of the following are to be notified of a scheduled outage?
   a. Hospital administration
   b. House staff
c. Referring physicians
d. All of the above
e. None of the above

3. Which of the following is a NOT a downtime due to software failure?
   a. Virus
   b. Driver installation
   c. Windows updates
   d. Video card
   e. Corrupt file system

4. Which of the following is a possible technical solution to minimize
downtime?
   a. Fault-tolerance PACS
   b. Multiple PACS workstations
   c. Backup system
   d. Full system backup prior to scheduled downtime
   e. All of the above

5. The procedure used to outline steps to utilize a second copy of image data
being stored in a separate location after a catastrophic event is an example of
   a. Disaster recovery procedure
   b. Incident report
   c. Scheduled downtime procedure
   d. Modality downtime procedure
   e. Infrastructure downtime procedure

6. List several methods of communication for scheduled and unscheduled
downtimes.

7. Describe some examples that might constitute a single point of failure.

8. Explain why decision criteria are necessary when considering whether to
switch to a backup system during a downtime.
Part IV
Operations : Infrastructure and Environment
Associate Editor: Scott Griffin
Chapter 16
Reading Room Design

Bill Rostenberg

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16.1 Introduction

One consequence of the transition from film-based to digital image capture, review, and transmission is the growing concern about improperly designed reading rooms and related spaces where digital images are displayed. Because softcopy image interpretation involves a more active interrogation than does hardcopy reading, it poses a greater reliance on a properly designed reading environment. Ramifications of poorly designed space and user interface include reduced interpretation speed and accuracy as well as job-related injuries including headaches, repetitive stress injuries, and fatigue.

The purpose of this chapter is to provide an overview of design considerations that should be included in reading rooms in order to optimize the performance of professionals working within such environments. Each consideration is applicable to both new design and renovation, although renovation projects may pose greater challenges to incorporating them, depending on the particular existing conditions of each project.

Environments designed for image display include spaces other than reading rooms. These consist of 3D reconstruction and visualization labs, PACS displays in the operating room, and referring physician PACS viewing areas.
Where appropriate, this chapter includes suggestions for improving the design of these areas.

16.2 Challenges of Reading Room Design

The challenges of designing reading rooms that optimize users’ performance are numerous. These include both the process of collaborating with the design team who is designing your space and understanding specific physical elements that affect reading performance.

16.2.1 Educating the Design Team

- Be sure your design team understands both the importance of the reading room and the activities that take place therein.
- Historically, many hardcopy reading rooms have gone un-designed or have been designed as generic offices with lighting and finishes inappropriate for reading. In many cases, radiologists have been able to compensate for this by turning the lights off and modifying the room slightly.
- Softcopy reading is more greatly influenced by design of the space and thus, postconstruction modifications are more difficult and often less effective than for hardcopy reading areas.
- It is desirable that the radiologists and others working with the design team have a unified vision of how they prefer their reading room(s) to operate (i.e., private offices, small groups, large groups, etc.).

16.2.2 Room Enclosure

- First determine your preferred reading environment. There is usually a need for both visual and...

Further Reading 16.1

Definition 16.2: Reading Room/Reading Area
Defined space containing one or more work areas.

Definition 16.3: Work Area
Zone including PACS monitors and computer system; one or several people seated or standing reviewing the same set of images and data (note: architects often refer to a workstation as being the same as a work area; radiologists often refer to a workstation specifically as the PACS equipment).

Further Reading 16.4
acoustic privacy (spatial separation) while at the same time having a need for extensive collaboration with co-workers (spatial openness). Completely solving one need will likely compromise the other. At one end of the spectrum, a private office provides privacy with less ability to collaborate. At the other extreme, old style “ballroom” reading rooms (common when only one “film” image was available) provide a high degree of collaboration, but little privacy and much chaos.

- Unless private offices are desired, consider subdividing a moderately sized space into smaller work areas using modular furniture.

1. Each work area can accommodate a variety of individuals collaborating at one workspace. Typically, a workspace designed for 1–2 people seated with adequate space for occasional groups of 4–6 individuals standing is desirable. This arrangement can usually be accommodated within a minimum of approximately 60–90 net square feet (NSF) of floor space. More space may be allocated for more generous accommodations. In contrast, a private, modestly sized single occupancy office is often approximately 90–110 NSF.

2. Generic “clerical” furniture may not provide adequate lighting control that is necessary for reading activities. Provide additional acoustic control or select furniture designed specifically for radiology reading use.

3. Avoid built-in casework. Ergonomically designed fully adjustable furniture is preferable (see “ergonomics” below).

4. Consider a workspace that accommodates more people for academic medical centers.

5. Room configuration and orientation of workspaces within the room will affect the ability of the various occupants to interact with each other as well as the ability to control lighting and acoustics.

- Placement of workstations along the room’s perimeter requires the least amount of space, but also provides the least amount of acoustic and lighting control.
Conversely, arranging the workspaces in the room’s center requires additional space, but provides better opportunities to control lighting and acoustics.

Where image viewing takes place outside of the reading room – such as at a PACS review station in the Emergency Department, ICU, or a general acuity Nursing Unit, special care must be taken to prevent clinical data from being seen by others, in violation of HIPAA regulations.

16.2.3 Lighting

- Improper lighting can lead to eye fatigue, headaches, and other occupational injuries as well as suboptimal reading quality.
- Each work area within a reading room should have individual controls. All lighting should be dimmable.
- Fluorescent lights may cause flickering. Consider incandescent, halogen, or led lights.

Key Concept 16.8: Lighting

Lighting control is the reading room’s single most important design consideration.

Checklist 16.9: Ambient Lighting

- General illumination levels for computer tasks
- Illumination for reading tasks using localized light sources
- Balance of brightness levels in the user’s field of vision
- Control of monitor reflection

- Two distinct types of lighting are needed in the reading room.
  1. Dimmable ambient lighting
     - Provides low levels of evenly distributed background illumination for image interpretation.
     - The same light sources can be adjusted for higher illumination for maintenance and housekeeping activities.
     - Should have broad-beam coverage.
     - Indirect ambient lighting that bounces off a surface such as the ceiling is generally preferred over direct lighting where the source of illumination can be seen. A ceiling height of 9’6” or higher may be required for proper installation of indirect lighting.
     - Note: many building codes require that all occupied rooms have some lights remain on at all times the space is occupied to aid in emergency egress.
2. **Supplemental task lighting**
   - Should be narrowly focused.
   - May be mounted to work stations or be portable fixtures.

- **Veiling glare** (reflection of light sources on the monitor’s surface) should be minimized.
  - Flat panel monitors are less prone to veiling glare than are cathode ray tubes (CRTs), which have been mostly replaced by flat panels for primary reading stations.
  - Items in the room that contrast with the room’s color and tonal value as well as light sources and monitors themselves can cause veiling glare.

- **Room illumination levels** should be approximately equal to the illumination level of the primary reading monitor.
  - Thus, as new monitors become available with higher illumination output levels, the room’s ambient illumination level should increase.
  - **It is a misconception that the reading room should be excessively dark.** Wall and ceiling surfaces (as well as surfaces of computers and other equipment) should be neutral in color and nonreflective in finish.
  - Some reading rooms have been designed with green filters incorporated into the ambient lights, with the assumption that the green illumination improves visualization of data on flat panel monitors.
  - Ambient lighting should be provided in such a way that contrast between the monitor(s) and surrounding wall surfaces is not so great that it causes eyestrain, yet the room must be dark enough and free of glare that data on the monitor can be easily discerned.

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### Definition 16.10: Supplemental Task Lighting

Additional local lighting that enables manual tasks such as writing and paperwork without disturbing other room occupants.

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### Further Reading 16.11


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### 16.2.4 Acoustics

- Acoustic control within the reading room has always been an important issue. In recent years, with the advent speech recognition and structured reporting, it has further grown in importance.
- Two types of sound should be addressed.
1. **Noise** from computers and other sounds originating from within the reading room can be annoying and can detrimentally affect speech recognition systems.

2. Discernable **conversations** are perhaps the most distracting kind of sounds originating from within the reading room. Overheard conversations make it difficult for radiologists to concentrate on activities of reading and image interpretation and thus, detrimentally affect reading accuracy and speed.

- Where image viewing takes place outside of the reading room – such as at a PACS review station in the Emergency Department, ICU, or a general acuity Nursing Unit, special care must be taken to prevent clinical conversations from being overheard by others, in violation of HIPAA regulations.
- It is difficult to provide complete acoustic control unless the reading room is a single-occupancy private office, but some degree of controlling sound can be achieved in rooms housing several work areas.
  - Noise travels either through the air or through wall and other surfaces.
  - Noise can be controlled by utilizing sound absorbing materials for wall, floor, and ceiling finishes as well as by utilizing **sound-absorbing partitions**, either fixed or movable.
  - Sound transmission is also influenced by the shape of the room.
  - Sound masking systems, sometimes referred to as “white noise,” can “scramble” discernable conversation preventing it from becoming distracting intelligible sentences as described above.

- Sometimes the sound of air passing through heating, ventilating, and air conditioning (HVAC) ductwork is adequate to scramble discernable conversation.
- In other instances, noise-canceling and scrambling hardware may be provided by furniture vendors.

- **The ceiling is typically the one surface that will have the greatest influence on sound transmission in a room.** Thus, its configuration, construction, and material composition are important.
- Where possible, **irregularly shaped rooms** – especially where opposite walls are not parallel to each other – will minimize sounds from bouncing or “reflecting” from one wall to another. However, irregularly shaped rooms may pose challenges of efficiently laying out workstations.

### 16.2.5 Ergonomics

- Radiology reading is an intense **repetitive process**, and as such the radiology professional may be subject to work-related repetitive stress injuries, especially if the reading room and its furnishings are not ergonomically designed.
• Reading workstations may be **shared by several individuals** of varying size, shape, and age. Thus, each physical element (work surface, chair, monitor, input device, etc.) comprising the workstation should be capable of various adjustments and positions.

• Even if only one individual uses a given workstation, it should be capable of a range of adjustments to prevent fatigue during a work session.

• Consider reading in a variety of positions including seated, standing, and reclining.

• Three **points of contact** should be considered when designing an ergonomic work environment.
  1. Where the eyes meet the monitor
  2. Where the hands and fingers contact the input device (if the input device is hand operated)
  3. Where the body rests against the chair

• Compared to other types of functions relying on computer input via keyboard and/or mouse, radiology reading may use **alternative input mechanisms**, such as speech, foot control, or a variety input devices derived from the electronic gaming industry.

• Eye problems related to radiology reading may be a result of both poor lighting and poor ergonomic design, such as improper distance from the eye to the monitor.

• Proper dimensions (such as seat and work surface height) and range of adjustments should conform to guidelines established by the Human Factors Society (HFS) and the American National Standards Institute (ANSI).

• Avoid built-in work counters and other types of work fixtures that do not provide an extensive range of adjustments.

• The reading room configuration and its furniture should **accommodate future developments** in reading processes and technology, such as the possibility of projecting images on wall surfaces or surfaces other than monitors, and the potential use of visual or holographic headsets. Virtual reality and visual immersion studios, while in limited use today, may become more common in the future.

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**Further Reading 16.12**


16.2.6 Connectivity

- Disorganized wires and cables connecting various components of the reading station can be distracting and can even pose tripping hazards.
- Many modular furniture systems include integrated cable management systems.
- **Wireless components** may reduce cable clutter, but they may also pose security and transmission interference challenges.
- Consider placing **frequently used devices** – telephones, dictation handsets, etc. – within close reach of the operator and in a way they can be used intuitively without having to remove one’s eyes from the data screen.

Further Reading 16.13


16.2.7 Thermal Comfort

- Thermal comfort can influence one’s ability to work efficiently and is a significant workplace satisfier or dis-satisfier.
- Temperature ranges for thermal comfort vary considerably among individuals.
- If possible, provide **individual controls** for each workstation’s control of temperature and air flow volume.
Some furniture manufacturers provide options for temperature and air flow controls to be built into their workstation furniture.

Checklist 16.14: Reading Room Design

- Room enclosure
- Lighting
- Acoustics
- Ergonomics
- Connectivity
- Thermal comfort

Pearls 16.15

- Radiologists who will use the reading rooms should work closely with the design team to establish a unified vision of how the room will operate. Agree on the nomenclature used in the planning to avoid any misunderstandings.
- Carefully consider room enclosures and adjustable furniture because visual and acoustic privacy are as important to provide as are collaborative work areas. Balance the space to accommodate a variety of individual users and occasional groups, being sure to reflect the unified vision.
- Pay attention to ergonomic standards that reduce work-related injury and increase level of accuracy in reading images. Furniture specifically designed for radiology reading is available.
- Ambient lighting should be dimmable and calibrated to match the brightness levels of the reading monitors, especially as they are upgraded over time. Task lighting should be narrowly focused and easily adjustable. Finishes should be neutral in color and glare free wherever possible.
- Keep in mind patient confidentiality, adhering to the HIPAA regulations where image viewing takes place outside of the reading rooms.

Self-Assessment Questions

1. What is the most important furniture consideration?
   a. Visibility
   b. Sterility
   c. Adjustability
   d. Sustainability
   e. None of the above

2. Which of these is not an ergonomic design consideration?
   a. Where eyes meet the monitor
   b. Where hands and fingers meet the input device
c. Where body rests against chair
d. Where ears meet the door
e. None of the above

3. What type of light is not recommended for reading rooms?
   a. Fluorescent
   b. Incandescent
   c. Halogen
   d. LED
   e. None of the above

4. What surface in the reading room has the greatest influence on sound transmission?
   a. The door
   b. The window
   c. The wall
   d. The ceiling
   e. None of the above

5. What amount of light is ideal for a reading room?
   a. Complete darkness for image viewing
   b. As bright as the monitors
   c. Daylight only
   d. An adjustable variety of light sources
   e. B and D

6. Which of these is not one of the benefits of spatial separation in the reading room environment?
   a. Visual privacy
   b. Acoustic privacy
   c. Ability to work independently with minimal distractions
   d. Less space for collaborating with others
   e. None of the above

7. Which of these are ways of providing acoustic control within a shared reading room?
   a. Sound absorbing materials for wall, floor, and ceiling finishes
   b. Sound masking systems
   c. Ceiling design
   d. All of the above
   e. None of the above

8. What are some of the ramifications of poorly designed space and user interface?
   a. Reduced interpretation speed
   b. Reduced accuracy
c. Job-related injuries
d. All of the above
e. None of the above

9. What is one of the causes of veiling glare?
   a. The room’s color and tonal value
   b. Ergonomic chairs
   c. Air conditioning
   d. All of the above
   e. None of the above
Chapter 17
Workflow Testing and Workflow Engineering

Barton F. Branstetter IV and Matthew B. Morgan

17.1 Introduction
When there is too much work and too few personnel, there are two main options: hire more staff or improve the efficiency of the existing employees. Generally, it is much cheaper and more satisfying to improve efficiency by identifying and removing workflow bottlenecks.

17.2 Workflow Testing
Although accurate workflow analysis can be a somewhat tedious and time-consuming task, it is a critical step in understanding how to improve a process.

Definition 17.1: Workflow
The steps that employees perform as they are getting their work done, and the relationships between those steps.

Definition 17.2: Workflow Bottleneck
The most inefficient step in a process; the step that defines the maximum rate at which the entire process can proceed.
17.2.1 How to Test

1. Survey
   - Fast and easy source of information
   - May be formal (online or paper survey) or informal (division meetings)
   - Can identify **perceived problems** (“pain points”) as well as **measurable inefficiencies**
   - Low response rates (25–30% is typical)
   - Notoriously inaccurate – what workers *say* they do is often not what they *really* do
     - What managers say that their employees do is even less reliable
   - Biased – people with “an axe to grind” and/or people who are most satisfied may be more likely to respond.

2. Direct observation
   - Easier than time–motion studies
   - Provides more reliable information than surveys
   - Not quantifiable (but may not need to be)
   - Should be performed by someone who is familiar with the job (ideally someone who has worked in that job)

3. **Time–motion study**
   - The most scientific approach
   - Provides quantitative data
   - Time-consuming

4. Advanced workflow testing
   - **Six Sigma** methods
     - DMAIC = Define, Measure, Analyze, Improve, Control
     - DMADV = Define, Measure, Analyze, Design, Verify
   - Pareto analysis
     - Assumes that 80% of delays are caused by 20% of workflow elements
     - **Pareto graphs** can focus attention on key workflow steps

Further Reading 17.3: Workflow
Chapter 5 describes the specific workflow steps for radiology employees; this chapter provides information about measuring and redesigning workflow.

Pertinent Quote 17.4: Survey Inaccuracy
If you asked a gorilla what he would like for his next evolutionary step, he would answer, “bigger muscles and longer fangs.” He would not ask for a larger cranial capacity.

– Rudy Rucker

Key Concept 17.5: Time–Motion Study
A formal workflow analysis tool that measures the amount of time spent (and wasted) on every workflow step.
Step-by-Step 17.6: Time–Motion Study

1. Videotape the worker doing her job.
2. Play the video and make a list of every workflow step that the worker performs, no matter how seemingly trivial (e.g., scans barcode).
3. Replay the video again, using a stopwatch (or video timer) to measure the exact amount of time spent on each step.
4. The total amount of time allotted to each step should exactly match the total time working.
5. Analyze the process to discover bottlenecks and pain points.

Definition 17.7: Six Sigma

A systematic method for preventing errors in service-related processes by using information and statistical analysis. Six Sigma relies on uniform workflow, which limits its applicability to physicians with idiosyncratic workflow.

Further Reading 17.8: Advanced Workflow Testing


- **Value Stream mapping**
  - aka Toyota Production System
  - Make a diagram showing the current steps, delays, and flow of information and personnel
  - Highlight bottlenecks

- **Run-sequence plot**
  - Graph key workflow metrics (e.g., number of undictated cases, average patient wait time) for each hour of the day
  - Identify times of day or situations where workflow efficiency is hindered

- **Prioritization matrix**
  - Quantify each pain point in terms of frequency, severity of impact, and feasibility of correction
  - Allow you to determine which projects to tackle first
  - Use “low-hanging fruit” (high impact, easy to fix) to build employee confidence in the concept of workflow engineering
17.2.2 Who to Test

- People whose jobs are most time sensitive (e.g., higher paid employees).
- Personnel performing the main function of the department (obtaining and interpreting images) are higher priority.

1. Highest yield
   - Radiologists
   - Technologists
   - IT support personnel

2. Somewhat useful
   - Administrative personnel
   - Clinical support personnel

17.2.3 When to Test

- Now, if you have not already (be proactive)
- **Change in technology** (e.g., introducing PACS, new PACS vendor, digital radiology, paperless workflow)
- New IT department
- Major personnel change
- Complaints from personnel about inefficiencies
- Complaints from customers (better late than never, but you should avoid this reactive approach)

Further Reading 17.9:
Digital Radiology Workflow

17.3 Workflow Engineering

17.3.1 Workflow Enhancements

1. Customization
   Workflow should be optimized for each working environment. Workflow that is optimal under certain circumstances may be inadequate with slight changes in working environment. Optimization can be considered at multiple levels:
   - **User**: Knowledge workers should be able to adjust ergonomics of workspace, presentation/appearance of software, and communication tools and to reflect their own idiosyncratic needs.
• **Modality:** The workflow that is best for CT scanners differs from that needed for digital radiographs. Similarly, inpatient vs. outpatient scanners; in-hospital vs. imaging center scanners.

• **Division:** Workflow optimized for neuroradiology may not be optimal for musculoskeletal imaging.

• **Department:** Radiologists require workflow focused on “which scans require interpretation,” whereas clinical departments are focused on those patients who are currently in-house, or currently in the clinic, regardless of whether the images have been formally reviewed.

• **Hospital:** Large academic centers have different workflow than small private hospitals, and different hospitals may have local idiosyncrasies of hospital culture that define workflow.

• **Enterprise:** Geographic and cultural differences prevent us from taking workflow from one institution and applying it to another institution without local modifications. Major software vendors often overlook the need for this level of customization.

• **Patient throughput vs. information throughput:** It is important to not only optimize the flow of patients through the department, but also the flow of information.

2. **Integration**

   Whenever a worker must change from one work environment to another, there is a disruption in workflow, a potential to introduce error, and a degradation in efficiency.

   • Moving from room to room.
   • Moving from one computer to another (from a scanner to a nearby computer, or from the PACS workstation to a postprocessing workstation).
   • Switching between software applications on a single computer.
   • The **integration of multiple software systems** (PACS, RIS, dictation, EHR) into a single, unified working environment is particularly important for radiologists.
   • Integrating the Healthcare Enterprise (IHE) is a national initiative focused on improving the way computers share information through coordinating the use of established standards. Decision makers in imaging informatics should be familiar with IHE and insist that software vendors comply with the established standards.

3. **Dashboards**

   • Dashboards combine key indicators from multiple systems into one unified view to support decision making.
   • Digital dashboards summarize the state of a complex work environment so that workers can remain aware of potentially overlooked events or unsuspected failures.
Dashboards are customized to provide different information to different workers (e.g., radiologists need to know how many unread cases are on the PACS, whereas IT personnel need to know if hard drives are becoming full).

Dashboards can be developed by in-house software engineers. Some vendors are starting to incorporate dashboard features into their products.

4. **Load balancing**

   Maximum efficiency can be achieved if the work can be distributed equitably between workers. It is undesirable to have some personnel overworked while others are idle. There are practical limitations on how much of the work can be conveniently distributed, but there are also software implementations that can assist with load balancing, and these should be investigated.

   - Load balancing does not apply only to workers, but to all resources in the enterprise, such as computer servers and networks.
   - If possible, patients should also be load balanced between sites of care.

5. **Asynchronous communication**

   Traditionally, knowledge workers have relied on communication models that require both parties to be available at the same time (such as in a

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**Checklist 17.10: Systems that Should Integrate with PACS**

1. Speech recognition/dictation
2. Postprocessing/advanced visualization
3. Clinical decision support tools (e.g., online knowledge bases)
4. Communication tools (phone lists, preliminary report tools, protocoling software)
5. Teaching files
6. Clinical data sources (RIS, HIS, EMR)
7. Clinical dashboards

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**Definition 17.11: Dashboard Display**

A graphical interface that summarizes input from many sources into a small visual area that can be quickly understood. More detailed information is available by expanding individual elements of the dashboard.

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**Further Reading 17.12: Dashboards**

When workers can instead communicate at their convenience, each worker can minimize the disruption to his own workflow.

Examples in radiology:

- Radiologists communicating preliminary or unexpected results to referring clinicians.
- Technologists requesting protocol or other scanning information from radiologists.
- Electronic messaging software can be integrated into radiology and clinical workflows to support asynchronous communication.

6. **Base case** workflow design

Software systems are often designed such that any conceivable functionality is always immediately available. This creates confusing interfaces, because the most frequently used options are hidden in a sea of rarely needed features. Workflow should be designed to address the base case; this may result in rarely needed tasks becoming more difficult to access, but will save time on average.

7. Defined roles

- Each worker should have well-defined responsibilities.
- These responsibilities should cover all the needed tasks.
- Minimize overlap between workers’ responsibilities.
- Failing to do this allows workflow gaps, and tasks may fall through the cracks.

8. Redundancy

- Redundancy is critical in clinical personnel, just as it is in IT systems.
- Cross-training clinical personnel is essential to assure that all work can be performed regardless of scheduling (i.e., if only one individual knows how to perform a particular task, then the task cannot get done when that individual is unavailable).
- It is acceptable to have experts or superusers, but critical workflow-dependent knowledge should be shared.
9. Intuitive workflow design
   • Make it easy to do the right thing – the path of least resistance should correspond to the desired workflow.
   • Workers who must jump hurdles to perform workflow tasks will find workarounds that may subvert the intended workflow.

10. Appropriate workspace layout
   • Often-used devices and computer should be placed near to each other.
   • Minimize the distance that a worker needs to travel, especially for often-repeated tasks.

17.3.2 Workflow Bottlenecks

1. Extra steps
   Small workflow inefficiencies are easy to overlook, and may not be important for infrequent tasks. However, a small inefficiency that is repeated dozens of times per day is frustrating and inefficient.
   Examples in radiology:
   • Manual hanging protocols requiring the same step over and over again.
   • Unnecessary dictation steps (i.e., repeating the medical record number, patient name, type of exam, etc.).
   Potential solution: work with vendors to eliminate extra steps

2. Paper tokens
   If your department needs to pass a piece of paper from person to person in order to continue the workflow, the paper can get lost, or workers can be idle waiting for the paper when they could instead be completing the next task.

Synonyms 17.16:
Intuitive Workflow
• Dummy proofing
• Mistake proofing
• “Path of least resistance” workflow

Hypothetical Scenario 17.17:
Small Inefficiencies
The radiologist needs to launch comparison cases on every patient, because they do not launch automatically. The cost is only a single mouse click per patient, but if the radiologist reads hundreds of cases per day, it adds up.

Definition 17.18: Workflow Token
Reminder or indicator that a workflow task requires attention. Usually a physical object passed from one person to another. Examples: paper exam requisitions, typed dictations to be signed.
• Potential solution: implement a “paperless workflow” to decouple radiologist and technologist workflows.

3. Out-of-band tasks

• Workflow steps that are infrequently performed, or are not part of the usual workflow, are easily overlooked.
  • Example: Signing reports in a separate application (RIS) when the majority of the radiologist’s time is spent in the image interpretation environment (PACS).
  • Especially true if more than one person shares responsibility for the task.
• Potential solution: Implement a “digital dashboard” that tracks key indicators and facilitates task prioritization and task switching.

4. Manual data entry

• Slow and prone to error (fat-finger errors)
  • Example: typing a medical record number into a scanner
• Potential solution: population of data fields should be automated (for example, with IHE)

5. Interruptions

  Although some are unavoidable, distractions and/or interruptions are a problem for knowledge workers who are performing complex tasks. At best, they reduce efficiency, and at worst, they may cause cognitive errors due to lapses in attention.
  • Examples include phone calls, pages, software alerts (e.g., email)
  • Potential solutions
    • Minimize workflow interruptions by assigning one worker to triage phone calls.
    • Implement asynchronous communication models where appropriate.

6. Task switching

• Moving between separate and/or isolated computers or software systems reduces efficiency.
• Potential solution: integration of software and hardware decreases wasted movement.

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**Definition 17.19: Out of Band Task**
A task that is not part of the routine workflow, and must instead be performed while normal workflow is suspended. Workers often neglect out-of-band tasks.

**Definition 17.20: Fat Finger Error**
Manual typing is inherently error-prone, especially when the data are numerical. Fat-finger errors are typographical errors that could be avoided by prepopulating data fields.
7. Low **Signal-to-Noise Ratio**

Though most often applied to the physics of image acquisition and display, the concept of signal-to-noise ratio can also apply to a work environment.

- The complexity of a working environment can reduce the ability of knowledge workers to prioritize new information. An example of this occurs when urgent studies are “lost” in a long list of routine studies.
- Flags can be used to alert users to high-priority tasks.
  - Workers must be able to trust that a signal to perform a workflow task is reliable. If a worker is sent on a wild goose chase by an incorrect flag, that worker will learn to ignore the flag.

**Definition 17.21: Flag**

Reminder or indicator that new data are available. Usually, an auditory or visual cue within a software program. Example: “You have mail!”

**Pearls 17.22**

- When there is too much work, you can either hire more people or improve efficiency.
- What people say they do is not necessarily what they really do.
- Any major change in technology merits a workflow analysis.
- The “Holy Grail” is the integration of all workflow onto a single workstation.
- Workflow must be customized to different individuals and different work environments.
- Integration of different software applications can boost workflow efficiency.
- Frequently performed tasks by highly trained/paid individuals should receive the most attention when redesigning workflow.
- Interruptions and distractions are the largest barriers to efficient workflow.

**Self-Assessment Questions**

1. Which of the following is the LEAST reliable method of workflow analysis?
   - a. informal discussions
   - b. formal surveys
   - c. time–motion studies
   - b. direct observation

2. Which of the following workflow problems should receive the most attention?
   - a. Low-frequency, high-time-commitment tasks
   - b. Pain points
c. Administrator workflow
d. All of the above are equally important

3. All of the following enhance workflow EXCEPT:
   a. Dashboards
   b. Base case workflow design
   c. Redundancy of key personnel
   d. Paper tokens

4. Which of the following scenarios is most appropriate for asynchronous communication?
   a. Alerting an emergency department physician to emergent radiologic findings
   b. Consulting a radiologist for an allergic contrast reaction
   c. Communicating the need for a 6-month follow-up examination
   d. Asynchronous communication is appropriate for all of the above

5. Which of these changes should prompt a workflow analysis?
   a. Introduction of new technology
   b. Major personnel change
   c. Complaints from personnel about software inefficiencies
   d. All of the above

6. Imagine that your department installs digital radiography equipment that can perform X-rays five times faster than traditional equipment. You will have to redesign workflow for many different workers: radiologists, technologists, administrators, and even patients. Which of these is the most critical to take best advantage of your new equipment?

7. Describe how you would perform a time–motion study of a CT technologist.

8. If you were a gorilla, what would you choose as your next evolutionary step?
Chapter 18
Policy Management and Regulatory Compliance

David E. Brown

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18.1 Introduction

Policy management and regulatory compliance extend well beyond administrative management and touches all levels of an organization. The role of an imaging informatics professional is to be knowledgeable on organizational, local, state, and federal requirements and to assure that his area of responsibility is in compliance with these requirements. This chapter covers the most significant federal regulations that currently impact the imaging informatics professional. The chapter ends with a review of the requirements for professional certification in imaging informatics.
18.2 HIPAA

18.2.1 Overview

- **Health Information Privacy and Accountability Act of 1996**
  - Healthcare reform act adopted by the U.S. Congress to provide for the protection and portability of health insurance coverage when changing employers or losing jobs.
  - Required provisions to protect against healthcare abuse and medical fraud.
  - Required that personal health information be protected and kept confidential.
  - Required the establishment of national standards for the management of protected health information.
- HIPAA is comprised of the following five titles:
  1. Health Information Reform
  2. Administrative Simplification
  4. Application and Enforcement of Group Health Plan Requirements
  5. Revenue Offsets.
- Title II specifically addresses the protection of PHI and has significantly impacted how healthcare providers handle PHI throughout the United States.

### Checklist 18.2: PHI

- Names
- Geographic subdivisions smaller than a state, Geocodes (e.g., zip, county, or city codes; street address, etc.)
- Dates. All elements of dates except year, unless individual is >89 years. (e.g., birth date, admission date, etc.)
- Telephone numbers
- Fax numbers
- Electronic mail addresses
- Social security numbers
- Medical record numbers
- Health plan beneficiary numbers
- Account numbers
- Certificate/license numbers
- Vehicle identifiers and serial numbers (including license plate numbers)
- Device identifiers and serial numbers
18.2.2 Title II: Administrative Simplification

- Title II focused on protecting against medical fraud and abuse by increasing efficiency and effectiveness of the healthcare delivery network by establishing requirements addressing the management of electronic healthcare information.
- Title II required that the Department of Health and Human Services (HHS) define national standards for Administrative Simplification.
- HHS defined five rules addressing Administrative Simplification: the Privacy Rule, the Transactions and Code Sets Rule, the Security Rule, the Unique Identifiers Rule, and the Enforcement Rule.
- The rules that have most significantly impacted imaging informatics professionals are the Privacy Rule and the Security Rule.
- The Privacy Rule went into effect in 2003 and established national standards on the use, disclosure, and protection of health information.
- The Privacy Rule pertains to protected health information (PHI) in any format, including hardcopy and electronic representations.
- The Privacy Rule specified that “covered entities” included any healthcare entity that transmitted health information in electronic format, including business associates of the entity.
- The Security Rule went into full effect by 2006, sets standards for the management of protected health information in electronic format (ePHI), including confidentiality, integrity, and availability.
- Enforcement of the HIPAA Security Rule was authorized to The Centers for Medicare and Medicaid Services (CMS).
- The Security Rule includes both standards and implementation specifications. Implementation specifications are either required or addressable.
- Required implementation specifications must be implemented.
- Addressable implementation specifications require an assessment to determine if the addressable safeguard is reasonable and appropriate in the given environment. If the safeguard is determined to be unreasonable and

Hypothetical Scenario 18.3: Celebrity Health Records for Sale

Suppose an employee was selling celebrity health information to the tabloids from your facility. Would this be detected? Do you have written policy on how to handle this breach?
inappropriate, then documentation is required to justify the decision. Equivalent alternatives must be considered in the assessment.

- It is the experience of this author that during an HIPAA security audit, both required and addressable implementation specifications will be examined closely by the Office of the Inspector General.
- The Security Rule identified three safeguards for compliance: administrative, physical, and technical.
- **Administrative safeguards** include security management, assignment of security responsibility, risk analysis and management, information access management, security awareness and training, security incident procedures, data backup and recovery plans, and written security contracts with business associates.
- Security management requires the implementation of policies and procedures addressing the prevention, detection, containment, and correction of security violations.
- Assignment of security responsibility requires the designation of an **HIPAA compliance officer** who is responsible for the development and implementation of security policies and procedures.
- The security team may also include a privacy officer and a security officer.
- All personnel should know their HIPAA compliance officer’s contact information, as well as contact information for the rest of the security team.
- **Risk analysis and management is required.** Include risk analysis on factors for each system that could affect confidentiality, availability, and integrity of ePHI.
- Periodic risk assessments are required due to the dynamic nature of technology and environment.
- **Document HIPAA compliance capabilities for each system,** including deficiencies and planned remediation. Describe measures being taken to reduce risks and vulnerabilities.
- Review of information system activity is typically accomplished using
  - audit logs
  - access reports
  - security incident tracking reports
- Information access management includes policy and procedure on the establishment, modification, and termination of access for authorized personnel.
- Information access authorization should provide appropriate levels of access based on job function.
- Demonstrated competency of an application as measured by competency tests should be required prior to providing access to the application.
Security awareness and training for the entire workforce who works with or has exposure to ePHI is required and should be established as an annual competency for personnel. It is important to publicize any possible outcomes for an employee in the event of a security breach if it is determined that the breach is willful or significant in nature.

Document system backup policy including patient data backups, database backups, and system backups. Include policy of periodic checks for readability of backup tapes and other media.

A formal, documented disaster recovery and contingency plan is required. Both catastrophic failure and system malfunction should be addressed.

Identify the disaster recovery manager and members of the disaster recovery team for each application and include contact information in the disaster recovery and contingency plan.

Business associates who have access to ePHI are required to sign a written contract or other arrangement regarding the protection of ePHI.

Checklist 18.7: Administrative Safeguards

- HIPAA compliance officer and team selected and contact information known to personnel.
- HIPAA compliance policies and procedures complete and up-to-date. Policies reviewed and updated on a regular basis.

  Recommended P&P:
  - Master list of HIPAA-related policies and forms,
  - HIPAA policy approval process,
  - Confidentiality policy,
  - HIPAA violation sanction policy,
  - Minimum access to information policy,
  - Minimum access job description documentation,
Physical safeguards include facility access controls and security plan, workstation use and security, device media control, and data backup. Physical safeguards must limit physical access to information systems containing PHI and the facility in which they reside, while allowing proper access to appropriate personnel. Document how physical access is limited to a system or application, including servers, workstations, and applications.

Workstation security includes the development of policies and procedures addressing appropriate workstation use and measures that can be taken to protect PHI. Safeguard against the inadvertent viewing of PHI by unauthorized individuals. Have computer monitors facing away from public view and use password-protected screen savers. Privacy screens are highly recommended in areas where unauthorized individuals may have the ability to view confidential information or PHI.

Device media control policies and procedures should address what is appropriate use of tapes, disk drives, removable drives, USB flash drives, CDs or DVDs, and any other devices or media that may contain PHI.

Document how PHI is eliminated prior to the disposal or relocation of electronic media containing PHI.

Data backup requires that documentation on how a retrievable, exact copy of ePHI will be created, when needed. Data backup is an addressable item prior to the movement of equipment.

- Privacy practices policy,
- System and database backup policy,
- Business continuity and disaster recovery policy.

- HIPAA compliance training of personnel performed on a recurring basis. Establishing training as an annual competency is recommended.
- HIPAA compliance validation and documentation on all systems and applications containing PHI.
- Signed contracts with business associates who have access to PHI assuring HIPAA compliance with regards to disclosure and protection of PHI.

Key Concept 18.8: Server Security

- Are your servers located in a secure environment, protected from tampering and theft?
- Do you limit access to server rooms using key cards or proxy card readers?
- Is the room temperature controlled?
- Are the servers protected from electrical power spikes and outages?
Technical safeguards include unique user identification, user account administration, emergency access procedures, audit controls, electronic data integrity, person and entity authentication, and transmission security.

User account administration includes the requirement that each user who has access to PHI have a unique user identification assigned. This provides a method for tracking individual users accessing PHI using audit logs.

User account administration includes establishing an approval process for account authorization, and standard procedure for removing access when personnel leave or transfer to another work area. Accounts must be suspended for personnel taking an extended absence.

Review all user accounts periodically to identify dormant accounts that can be deactivated or removed. Establish a procedure for the removal of these accounts.

Automatic logoffs should be employed that terminate a user’s session after a certain period of inactivity. This time can vary based on the function of the application. The inactivity period selected should be documented in policy and procedure.

Document emergency access processes for accessing a system or data when system cannot be authorized in a normal manner.

Audit controls should describe procedure for recording and examining system and application activity. Include the name of the person reviewing the audit logs and document items captured in audit logs.

**Key Concept 18.10: Audit Logs**

Audit logs should provide the following information:

- **Who?** User ID of person looking at PHI.
- **What?** Identify PHI viewed.
- **When?** Date and time viewed.
- **Where?** Unique PC station name that can be used to identify location.

Note: “Why?” will require follow up with the employee or employee’s supervisor.
Inform and remind employees of established auditing procedures on a routine basis. Annual review is recommended.

Establish procedure for backing up audit security logs.

Electronic data integrity includes establishing procedure that safeguards against the **improper alteration or destruction of PHI**. Identify users and user roles that have alteration and deletion privileges within an application or system.

Person and entity authentication addresses authentication of remote users or entities accessing applications or systems containing PHI. Authentication should include user logon challenges, token keys, smart cards, security certificates, etc.

Transmission security includes **integrity controls and the encryption of data** that are exchanged between two remote locations.

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**Checklist 18.11: Technical Safeguards**

- Establish unique user IDs for each application accessing PHI. Eliminate any generic user logons.
- Establish account authorization procedure including the factors determining the appropriate assignment of user privileges. Also, establish a procedure addressing the deactivation or removal of account access when personnel is transferred or terminated.
- Document configuration settings of PHI-related components for each health information system, including automatic logoff intervals, password retries, password aging, user account privileges, etc.
- Set up audit logging on all systems containing PHI and document pertinent information captured in the audit logs. Establish a procedure for backing up audit logs.
- Establish policy addressing remote access of PHI that includes authentication of remote user or facility, and secure transmission of PHI between remote locations.

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**18.2.3 State, Local, and Organizational Regulations**

**State, Local, and Organizational Regulations** must also be considered. These regulations can be more restrictive than federal regulations.

- An example of state regulations that have historically been more restrictive than federal regulations is legislation addressing the security and privacy of **social security numbers** (SSNs).
- In 2003, California passed Bill 1386 requiring companies to notify individuals when there is a security breach that compromised SSNs and other personal information.
- In 2004, Colorado passed H.B. 1311 that limited the collection of SSNs and established policies for the safe destruction of documents containing SSNs.
- In 2005, Arizona prohibited the disclosure of SSNs to the general public and established requirements for the electronic transmission of SSNs.
- An example of **organizational regulations** being more restrictive than governmental agencies could be a requirement that all transactions on the organization’s private network be encrypted.

### 18.3 MQSA

#### 18.3.1 Overview

- Regulated by the Food and Drug Administration.
- Establishes national standards for both film-based and digital mammography. Goal is that all women should have access to quality mammograms for the detection of breast cancer in the earliest, most treatable stages.
- Requires that all facilities providing mammography services are accredited, certified, and inspected annually.

#### 18.3.2 Accreditation, Certification, and Inspection

- Accreditation is performed by an **accreditation body** (AB) approved by the FDA. Accreditation bodies include the ACR at the national level, and States that obtained FDA approval. As of the date of this writing, the following States are accreditation bodies: Arkansas, Iowa, and Texas.
- Facilities applying for accreditation are either new applicants, applicants seeking reaccreditation, or applicants seeking reinstatement.
- New facilities will receive a **provisional MQSA certificate** when the AB has determined that all requested material has been received. During the 6-month period, clinical images and phantom images must be submitted to the AB, as well as other required material (Fig. 18.1).

**Key Concept 18.12: Accreditation and Certification**

All facilities must first be accredited by an accreditation body (AB) in order to be eligible for MQSA Certification. Upon completion of an accreditation evaluation, the AB will notify the Certifying Agency on eligibility status for certification.
If the new applicant passes review, the AB will notify the Certifying Agency and a full MQSA certificate will be issued. These certificates are effective for 3 years.

Facilities that have an accreditation that is expiring must apply for accreditation renewal with the AB. Upon approval by the AB, the Certifying Agency will issue the MQSA for another 3 years.

Facilities must apply for reinstatement if their accreditation has expired, accreditation was denied, certificate renewal was refused, or the certificate was revoked.

The facility applying for reinstatement must work with the AB to resolve deficiencies. The AB will review corrective actions. If review is passed, the AB will notify the Certifying Agency and a new provisional certificate will be issued that is effective for 6 months.

Changes in operational status must be reported to the AB. This include changes in ownership, address changes, personnel changes, and equipment changes.

Apply for accreditation whenever new units are added to a facility.

Certification is performed by a Certifying Agency approved by the FDA. Certifying Agencies include the FDA at the national level, and States that obtained FDA approval. As of the date of this writing, the following States are Certifying Agencies: Iowa, Illinois, South Carolina, and Texas.

The receipt and display of the MQSA certificate will allow a facility to perform mammography legally up to the date of expiration. Certificates are issued by the Certifying Agency after notification from the AB that the applying facility has passed accreditation.

There are three types of certificates: provisional, full, and 90-day extension. The 90-day extension can only be issued one time to a facility.

Fig. 18.1 MQSA Process.
• **Inspections** are performed annually by the Certifying Agency or one of its agents.
• Random onsite visits may also be performed by the AB, as well as random clinical image reviews.
• Inspection findings are classified in three categories according to deviation from MQSA standards:
  – Level 3 – facility performance satisfactory with minor deviation
  – Level 2 – facility performance acceptable with moderate deviation
  – Level 1 – facility performance unacceptable with serious deviation

### 18.3.3 Requirements

• **Accreditation and certification** require that certain standards be met regarding personnel qualifications, equipment standards, equipment performance, quality control testing, physics surveys and quality assurance testing, recordkeeping, reports to patients and physicians, records retention, medical outcome audits, consumer complaint mechanisms, and infection control.
• **Personnel qualifications** include physicians, technologists, and medical physicists.
• **Physicians** must be licensed to practice medicine in the State, and be certified in the interpretation of radiologic procedures, including mammography. Physicians must have at least 3 months of documented training in the interpretation of mammography, and a minimum of 60 hours of documented medical education in mammography.
• **Technologists** must be licensed to perform radiologic exams in the State, and completed 40 contact hours of documented training in mammography, including performance of a minimum of 25 examinations under the direct supervision of a qualified professional.
• **Medical physicists** must be licensed or approved by the State, and have certification in the appropriate specialty. A minimum of a Master’s degree in medical physics is required. Documented training must include a minimum of 20 contact hours in conducting surveys.
• **Continuing education and continuing experience** are required to assure that personnel maintain technical competence.
• Facilities must maintain personnel records documenting qualifications and current status of interpreting physicians, technologists, and medical physicists.
• **Equipment must be designed for mammography** and certified by the FDA.
• Mammography equipment evaluations are to be performed on new equipment or whenever there is a significant change to existing equipment, including replacing major components or equipment relocation.
Screening film requirements specify that x-ray film and intensifying screens shall be appropriate for mammography.

Equipment performance evaluation will require the submission of clinical images and phantom images for accreditation and certification review.

Accreditation requirements for clinical image review specify the submission of two mammographic exams from each mammography unit within a specified time period (typically 6 months). Only exams that were interpreted as negative or benign shall be submitted. One exam shall be from a patient with dense breasts (predominance of glandular tissue), and the other exam shall be from a patient with fat-replaced breasts (predominance of adipose tissue). Images shall include craniocaudal (CC) and mediolateral oblique (MLO) views.

Clinical image review will include the following: positioning, compression, exposure level, contrast, sharpness, noise, artifacts, and exam identification.

Requirements for full-field digital mammography specify that the entire breast must fit on images submitted for clinical review (tiling of images is not permitted), and that the images are printed “true size.”

Accreditation requirements include phantom image review of phantom images submitted from each mammography unit within a specified time period (typically 6 months).

It is assumed that the best examples of clinical and phantom images from a facility unit will be submitted for accreditation and certification review.

Daily, weekly, monthly, quarterly, and semiannual quality control (QC) testing is to be performed by a medical physicist, or a technologist under the supervision of a medical physicist.

Daily QC tests for screening mammography include a check for: base plus fog density, mid-density, and density difference.

A weekly phantom test must be performed to evaluate image quality.

### Checklist 18.13: Mammography Equipment Assessment Requirements

- Motion of image-tube receptor assembly
- Image receptor sizes
- Light fields
- Magnification
- Focal spot selection
- Compression device requirements
- Technique factor and display
- Automatic exposure control
- Laser quality control for FFDM

### Checklist 18.14: Mammography Patient/Exam Identification Requirements

- Patient name
- Second patient identifier
- Exam date
- View and laterality
- Facility name and location
- Technologist ID
- Cassette/screen ID
- Mammography unit (if more than one unit at facility)
Phantom image QC is to be performed according to the following guidelines:
1. same technique that is used for a 4.2 cm breast is to be used,
2. image processing is to be the same as is used for clinical images,
3. scoring is to be done for the largest fibers, speck groups, and masses,
4. rotation and zoom is not permitted, and
5. images are to be displayed “true size.”

**Quarterly** tests for screening mammography include a check for residual fixer retention in films.

**Semi-annual** QC tests for screening mammography include checks for darkroom fog, screen film contact, and compression device performance.

**Annual** QC tests include a check for automatic exposure control performance, kilovolt peak (kVp) accuracy and reproducibility, focal spot condition, beam quality and half-value layer, breast-entrance air kerma and AEC reproducibility, dosimetry, x-ray field/light field/image receptor/compression paddle alignment, uniformity of screen speed, system artifacts, radiation output, decompression, and QC tests of other modalities.

Facilities must maintain **complete and accurate records** on all QC/QA testing performed.

**Annual physics surveys and quality assurance** (QA) testing are required to ensure continued compliance and to provide oversight of QC/QA programs. These surveys are to be conducted by a medical physicist or by someone under the direction of a medical physicist.

The medical physicist is responsible for providing a survey report to the facility within 30 days of the survey date. The report shall include a summary of the survey and provide recommendations.

**The tracking of repeat and reject rates** must be reviewed quarterly. If a change greater than two percent of films examined is demonstrated when compared to the previous quarter, then the reason for this change needs to be determined.

**Content and terminology for patient results** to patients and physicians have been standardized and must include the (1) name of patient and second identifier, (2) exam date, (3) name of interpreting physician, and (4) overall assessment of findings.

The overall assessment of findings must be stated as one of the following: negative, benign, probably benign, suspicious, or highly suggestive of malignancy.

Communication of mammography results must occur within 30 days of the exam, or as soon as possible if the results are suspicious or highly suggestive.

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**Definition 18.15: BI-RADS**

Breast imaging – reporting and data system is a QA tool for mammography reporting.

**BI-RADS Assessment Categories:**

0 – Incomplete
1 – Negative
2 – Benign
3 – Probably benign
4 – Suspicious abnormality
5 – Highly suggestive of malignancy
6 – Known biopsy – proven malignancy
• Mammography films and reports shall be maintained for a minimum of 5 years, and no less than 10 years if no additional exams were performed at the facility. State regulations may require longer retention periods.
• Medical outcome audits must be performed on an annual basis. The audit will review the findings of all mammograms performed, and will follow up on any mammograms with positive findings. A correlation with pathology results and the interpreting physician’s findings is required. All audit data shall be reviewed annually by at least one interpreting physician.
• Each facility is required to have an established mechanism for handling consumer complaints. Serious consumer complaints that are not resolved by a facility must be filed with the accreditation body.
• Each facility is required to have an established infection control program.

18.3.4 Digital Mammography

• Full-field digital mammography (FFDM) can only be used at facility units that have been accredited and certified for mammography.
• Accreditation of FFDM devices is required if the device has been identified as having an associated accreditation body. Current accreditation bodies for FFDM include the ACR, Arkansas, Iowa, and Texas.
• For devices that require accreditation, the rules of accreditation apply. The accreditation process is the same as it is for screen film.
• For devices not associated with an AB, facilities must apply for a certification extension to permit the use of digital mammography equipment. Additional requirements must be met that are specific to digital mammography equipment.
• Personnel (interpreting physicians, technologists, medical physicists) must be qualified in FFDM, according to their respective roles. Personnel must have a minimum of eight hours of initial training in digital mammography.
• FFDM devices must have FDA approval. At the time of this writing, the FDA is proposing reclassifying FFDM from Class III to Class II devices. Digital mammography devices that have not been approved by the FDA are considered investigational devices.
• Facilities must meet the vendor’s recommended quality assurance standards for FFDM equipment.
• The FDA recommends that only FDA-approved monitors, printers,

Key Concept 18.16: FFDM Resolution

The native resolution for FFDM images are much higher compared to standard CR/DR. A resolution of at least five (5) line pairs per millimeter is required to view breast tissue in sufficient detail. Thus digital mammography devices such as display monitors, film printers, and film digitizers must be capable of supporting higher resolution outputs.
and film digitizers be used for digital mammography. Compliance with a QA program is required. In addition, any images produced by this equipment must pass image quality standards set by accreditation.

- The FDA requires that facilities have access to a laser printer before mammography can be performed. The printer must be tested and approved by a medical physicist as acceptable for the printing of mammographic images.
- Film digitization is to be done for comparison purposes only. Digitized film cannot be used in primary interpretation, nor can it be used as a substitute for the long-term archiving of the original film.
- It should be noted that if the original film is requested by the patient or her physician, the facility is obligated to provide the original film.
- It is permitted to electronically transfer images if acceptable to the receiving party. The data are to be transferred in their original state or using lossless compression only. The transfer of lossy-compressed images is not permitted.
- The long-term archival of FFDM data must be in its original format or as lossless-compressed data. The long-term archival of lossy-compressed images is not allowed.

Further Reading 18.17: Digital Mammography


18.4 Imaging Informatics Professional Certification

The purpose of professional certification is to allow employers to feel confident that the individuals they hire will have the skill sets needed to be successful as imaging informatics professionals. There are several organizations that offer certification programs for IIPs. For the purposes of this chapter, the CIIP test offered by the ABII will serve as an example of how certification programs are organized.

18.4.1 Overview

- Professional certification in imaging informatics is administered by the American Board of Imaging Informatics (ABII).
ABII was founded in 2007 by the Society for Imaging Informatics in Medicine (SIIM) and the American Registry of Radiologic Technologists (ARRT).

Successful completion of a national exam administered by ABII is required for an imaging informatics professional to become board-certified.

Certified Imaging Informatics Professionals are awarded the designation “CIIP.” Certification is valid for a period of 5 years. At the completion of 5 years, re-examination is required for renewal of certification.

ABII certification establishes a national standard of competency for demonstrated knowledge in imaging informatics.

18.4.2 Certification Exam Requirements

The criteria for determining an applicant’s eligibility for examination are based on a point system as well as meeting specific minimum qualifications.

The applicant must have a minimum of 2 years experience in healthcare imaging or imaging informatics.

Educational requirements include a minimum of 60 educational credit hours, or a minimum of an associate’s degree from an accredited college.

A minimum of 7 points in total is required, using ABII’s point system.

ABII’s point system awards one point per 12 months of experience in healthcare imaging or imaging informatics, up to a maximum of five points for experience.

Points for educational requirements include one point per 30 credit hours. An Associate’s Degree is awarded two points, a Bachelor’s Degree is awarded four points, and a Graduate Degree is awarded five points. The maximum number of points allowed for educational hours is five points.

IT or clinical credentials from an ABII-approved organization are awarded one point each, up to a maximum of two points.

Continuing education (CE) credits in imaging informatics are awarded one point per 18 hours of CE credit. The CE credits must have been completed in the 18-month period prior to the exam application date. The maximum number of points allowed for CE credits is two points.

18.4.3 Certification Exam Preparation

ABII published a test content outline (TCO) that defined 10 knowledge domains that were identified as required knowledge for professional certification in imaging informatics.

Identified knowledge domains include procurement, project management, operations, communications, training and education, image management, information technology, systems management, clinical engineering, and medical informatics.
The TCO was developed in a topic-nested-within-a-task framework. As such, the TCO lists key tasks associated within each knowledge domain, and then further lists topics associated with the identified tasks.

SIIM’s Education Advisory Network (EAN) developed learning objectives that are intended to serve as a standard for developing curriculum objectives for imaging informatics educational programs. These objectives can be found on SIIM’s website and are recommended review for anyone preparing for the CIIP exam.

As of the time of this writing, the EAN is developing a core curriculum outline that may serve as a standard to be used when developing imaging informatics educational programs. There is currently no established standard for the educational curriculum of imaging informatics programs and schools.

There are many avenues for applicants to prepare for the CIIP exam, including the ABII TCO, EAN learning objectives, the Journal of Digital Imaging, other healthcare information journals and publications, imaging informatics websites, PACS administration vocational training programs, and university-affiliated programs.

**Key Concept 18.18: Separation of ABII from Teaching Entities**

ABII is responsible for developing and maintaining a certification program, and defers curriculum development to SIIM’s educational committees, and other parties interested in imaging informatics education.

The development of the certification exam and the development of the educational curriculum are done independently by groups that are “firewalled” from each other to assure that test questions are not compromised. No educational body (including SIIM) can guarantee that their educational material will be representative of the questions found in the CIIP exam.

**Further Reading 18.19: CIIP Exam Preparation**

- ABII TCO. Available at: https://www.abii.org/ABII/faces/abii_test_content_outline.jsp
- SIIM EAN Learning Objectives. Available at: www.siimweb.org/ean
- SIIM Expert Hotline. Available at: www.siimweb.org/experthotline
- SIIM Imaging Informatics Professional (IIP) Bootcamp Training Manual. Available at: www.siimweb.org/iip
**Pearls 18.20**

- Protected Health Information (PHI) is any information that can be used to identify a specific individual. This includes obvious PHI like patient name and patient ID number. It also includes more obscure information such as study accession number and study date and time.
- Establish well-documented procedures for creating user accounts on applications that access PHI. Also, have a well-established procedure for deactivating accounts when users go on a long-term leave-of-absence, transfer to other work areas, or leave.
- Eliminate generic logons on all applications accessing PHI. Audit capability is severely compromised when the username is indeterminate.
- Keep servers housed in a secure environment. Security includes physical access to servers as well as environmental factors such as air conditioning and electrical power.
- Establish a disaster recovery and contingency plan. Disasters can be as catastrophic as earthquakes or hurricanes, or as catastrophic as a disk drive or database corruption!
- Have signed contracts with business associates assuring HIPAA compliance with regards to the privacy and security of PHI.
- MQSA certification is required for all facilities performing breast imaging.
- Screening film QC requirements are very well defined in MQSA. Facilities using digital mammography must meet applicable MQSA certification requirements for QC, and also meet digital mammography FFDM QC requirements as specified by the FFDM manufacturer.
- Content and terminology for breast imaging results have been standardized. BI-RADS is a commonly used QA tool for mammography reporting.
- Mammography repeat and reject rates must be tracked quarterly. Medical outcome audits must be done annually.
- Professional certification in imaging informatics is administered by the American Board of Imaging Informatics. There are specific requirements for certification eligibility, and competency must be demonstrated by successfully completing ABII’s certification exam.
- ABII has identified 10 knowledge domains that are requisite knowledge for certification as an imaging informatics professional. These domains include procurement, project management, operations, communications, training and education, image management, information technology, systems management, clinical engineering, and medical informatics.
- The ABII TCO and SIIM EAN learning objectives are excellent “starting points” when preparing for the ABII certification exam.
Self-Assessment Questions

1. Protected Health Information (PHI) is defined as
   a. All information that is available at the patient or study demographics level.
   b. Any information that can be used to identify an individual at the patient demographics level.
   c. Any information that can be used to identify an individual at the study demographics level.
   d. Any information that can be used to identify an individual at the patient or study demographics level.

2. The Privacy Rule pertains to protected health information in any format, and specifies that “covered entities” are defined exclusively as
   b. Healthcare entities.
   c. Healthcare entities and business associates.
   d. Healthcare payors.

3. The primary officer responsible for ensuring that an organization meets HIPAA requirements
   a. HIPAA compliance officer
   b. HIPAA privacy officer
   c. HIPAA regulatory officer
   d. HIPAA security officer

4. According to HIPAA, transmission security requires
   a. Integrity controls and the encryption of data that are exchanged between applications.
   b. Integrity controls and the encryption of data that are exchanged between local servers.
   c. Integrity controls and the encryption of data that are exchanged between remote locations.
   d. Integrity controls and the encryption of data are not required by HIPAA transmission security.

5. The Security Rule identifies three categories of safeguards for HIPAA compliance:
   a. Administrative, legal, and technical.
   b. Administrative, physical, and technical.
   c. Legal, physical, and technical.
   d. Authentication, encryption, and automatic logoffs.
6. The Mammography Quality Standards Act (MQSA) establishes national standards for mammography and is regulated by the
   a. American College of Radiology.
   b. Centers for Medicare and Medicaid Services.
   c. Department of Health and Human Services.
   d. Food and Drug Administration.

7. MQSA certification must be renewed
   a. Every year.
   b. Every 2 years.
   c. Every 3 years.
   d. Every 5 years.

8. The minimum native resolution for full-field digital mammography must be at least
   a. 1 line pair per millimeter.
   b. 2 line pairs per millimeter.
   c. 5 line pairs per millimeter.
   d. 10 line pairs per millimeter.

9. Which of the following is true regarding mammography films that have been digitized?
   a. Can be used for primary diagnosis and comparison studies and can be used as a substitute for film for long-term archiving.
   b. Can be used for primary diagnosis and comparison studies and cannot be used as a substitute for film for long-term archiving.
   c. Can be used for comparison only and not for primary diagnosis and can be used as a substitute for long-term archiving.
   d. Can be used for comparison only and not for primary diagnosis and cannot be used as a substitute for long-term archiving.

10. According to MQSA, it is permissible to electronically transfer mammography images specifically if
    a. The data are transferred in lossless compression format and are acceptable to the sending party.
    b. The data are transferred in lossless compression format and are acceptable to the receiving party.
    c. The data are transferred in lossy or lossless compression format and are acceptable to the sending party.
    d. The data are transferred in lossy or lossless compression format and are acceptable to the receiving party.
Chapter 19
Billing and Coding

Scott Griffin

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19.1 Introduction

As an imaging informatics professional, job requirements may be vastly different from location to location. In some locations, the imaging informatics professional may be solely responsible for all information systems, interfaces, workstations, and many other external systems such as transcription, whereas others may be partially responsible for a system while still having duties of a radiologic technologist.

Radiology coding and billing may be considered a dry subject material and the responsibility of the radiologists’ practice. However, a proficient IIP will be aware of the importance of the data exchange that is required to correctly code and bill for the worthwhile work performed by the radiology profession.

The implications of incorrect billing and coding are not just limited to decreased reimbursement. Billing agencies may uncover discrepancies during routine audits, or an audit may be triggered by questionable practices or persistent inconsistencies. Hospitals, imaging centers, and radiologists may be required to reimburse providers when mistakes are uncovered. Occasionally, criminal fraud charges are brought if errors are determined to be pervasive or deliberate.
19.2 Terminology and Standards

To begin with, it is important to become familiar with some of the crucial terminology of the coding and billing field; this material will be addressed in the order in which the data are normally provided or acquired.

As part of The Joint Commission’s National Patient Safety Goals, one of the required patient identifiers that are still used is the patient name. As most facilities can attest, this is not singularly the best method of identifying a patient, but in combination with their date of birth and/or medical record number the statistical likelihood of a patient being misidentified reduces greatly. These identifiers are in like manner used by billing and coding systems.

When a patient arrives at a healthcare facility, they are also assigned a medical record number (MRN) as well as an account/encounter number that assists in delineating which of the patient’s visits the data correspond to.

- The medical record number is assigned to each patient and is unique for each patient by facility. This number ensures that a patient is not mistaken for another patient with a similar name (i.e., John Jones) and is usually cross-matched with the patient date of birth.
- The International Classification of Diseases, ninth revision (ICD9) was developed by the international community to classify disease as well as determine mortality statistics. The ICD9CM is typically used by physician offices and hospitals to classify and code for diagnostic, therapeutic, and surgical

**Definition 19.1: Medical Coding**
The area of healthcare that focuses on accurately and efficiently completing the patient’s paperwork so that it may be submitted to the insurance carrier for reimbursement.

**Definition 19.4: ICD9**
ICD9 codes are used to classify medical diseases and a wide variety of signs, symptoms, abnormal findings, complaints, social circumstances and external causes of injury or disease.

**Further Reading 19.2: Radiology Coding**
- Clinical Examples in Radiology: A Practical Guide to Correct Coding (Quarterly newsletter published jointly by the AMA and ACR).

**Synonyms 19.3: Medical Record Number (MRN)**
- Unique patient identifier
- Patient ID
- Historically equated with social security number, but not since HIPAA
procedures. Depending on the facility an ICD9 code and current procedural terminology (CPT) codes are used to identify the exam that has been ordered. When coding and billing representatives verify data, the patient name, CPT, and date of service are vital in assuring that reimbursement will be granted by the carrier.

- CPT or current procedural terminology is utilized to ensure that the correct test or procedure is performed in conjunction with medical necessity.
- The Healthcare Common Procedure Coding System (HCPCS, commonly pronounced “hicks picks”) are often used to describe services rendered to a patient.

Once the procedure has been properly ordered and imaged, the radiologists will render his/her interpretation based on the information presented. On most occasions this will include:
- admitting diagnosis
- patient history from ordering provider or given by the patient to the technologists
- comparative data from other exams

This interpretation that is ultimately dictated and transcribed will be sent to the professional billing personnel who then compare it to the necessary demographics and codes that are submitted for reimbursement.

In some practices, the interpreting radiologist provides suggested CPT and ICD9 coding during dictation. In others, the professional billing personnel must gather and provide this information from what is included in the radiologist’s report:
- type of study
- body part(s)
- number of views
- administration of contrast
- patient history
- diagnosis

In these cases, it is vital that complete and correct information be included in the information sent to the coders to ensure that billing is accurate and complete. Newer software such as computerized physician order entry (CPOE), and some radiology reporting systems assist in proper coding at the time of order entry and report creation.

**Definition 19.5: CPT**

CPT codes are used to precisely classify medical, surgical, and diagnostic services and procedures. The CPT code tells what was done; the ICD9 code tells why it was done.
19.3 Required Practices

In many situations, coding and billing representatives identify incorrect correlation between the study required and the study actually performed that may have a negative effect of reimbursement. One example may be that a two-view chest x-ray has been ordered (in error) to verify line placement rather than a single view portable chest x-ray. In other situations, the coding and billing representatives may recognize that the radiologist’s report mentions one part of the human anatomy and the bill or charge has been created to reflect another. This happens frequently in healthcare with the use of correct or incorrect sides of the body (i.e., right vs. left). The implications of this common occurrence on reimbursement will be a denial of payment and a delay while the error is corrected.

Charges may be separated into components: technical, which is usually billed and collected by the healthcare facility, and professional, which is usually billed and collected by the radiologist practice. The division of billing between the technical and the professional services is complex and requires expert (and often legal) input to determine which bills are submitted by whom.

19.3.1 CPT Codes

An understanding of the American Medical Association’s CPT Codebook is an absolute requirement for coders. The CPT Codebook is a reference for daily issues and has a specific methodology to its overall structure.

The Standard Edition of the CPT Codebook is comprised of the following different categories of codes:

1. Evaluation and management
2. Anesthesia
Radiology is further subdivided into the following sections consisting of their own numerical scheme:

1. Aorta and arteries
2. Veins and lymphatics
3. Transcatheter procedures
4. Diagnostic ultrasound
5. Abdomen and retroperitoneum
6. Obstetrical
7. Nonobstetrical
8. Radiation oncology
9. Clinical treatment planning
10. Radiation treatment
11. Management
12. Proton beam therapy
13. Delivery
14. Hyperthermia
15. Clinical brachytherapy
16. Nuclear medicine
17. Musculoskeletal system
18. Cardiovascular system
19. Therapeutic

- There are additional subsets such as results/testing/reports, special reports, supervision and interpretation, administration of contrast material(s), and written reports.
- The format of CPT codes is five alphanumeric characters.
  - Category I codes consist of five numbers and describe a reimbursable procedure that is part of accepted medical practice.
  - Category II codes consist of four numbers and one letter and are used for tracking performance. They are not reimbursable.
  - Category III codes consist of four numbers and one letter and are used for experimental procedures. They are not reimbursable.
- In many cases, specific modifiers are used to ensure proper reimbursement is achieved.

Further Reading 19.7: CPT and ICD9 codes

- The AMA online bookstore has numerous publications regarding proper CPT and ICD9 coding, including many books specific to radiology.
More than one CPT code may be assigned to a single examination. This may or may not necessitate a separate radiology report.

Medicare reimbursement rates depend on CPT code and geographic area.

The AMA has an online search tool for CPT codes: https://catalog.ama-assn.org/Catalog/cpt/cpt_search.jsp

### 19.3.2 ICD9 Codes

ICD9 codes are used to describe diseases and symptoms that justify the need for radiology procedures.

- The format of ICD9 codes is an optional one-letter prefix, followed by three-digit number, followed by a decimal point, followed by up to two additional optional numbers (e.g., “372.25,” “E919.0,” “V84.01”).
  - Each additional number provides a more specific diagnosis, and usually results in greater reimbursement.
  - The prefix “E” denotes codes that describe an external source of injury (e.g., motor vehicle accident).
  - The prefix “V” denotes factors that are not true diseases, but influence a person’s health status or their effect on the health of others. V-codes have only two primary digits instead of three.
- More than one ICD9 code is often applied to a single examination.
- Unlike CPT codes, ICD9 codes are in the public domain, so a complete list can be downloaded from several sites. Make sure that you obtain the most recent ICD9-CM updates.
- ICD10 is in use outside the United States, and ICD11 is in development.

### 19.4 Information Transfer

In most cases the imaging informatics professional would have more involvement in correct information transfer than in any other area of coding and billing.

- Most coding and billing services will make use of specialized software that imports data to be combined in coding and billing.
- Based on the software program, these applications may import flat files that may be comma delimited or fixed width in nature, or they may utilize HL7 interfaces.
- When successful information transfer has occurred, the software application will import the demographics file and reports file into an application viewer so that coding review may take place in an efficient manner.
• In the event, the data do not arrive simultaneously the information may be held until its corresponding component is transferred successfully.

• In many cases, the necessary finalized radiology report may be delayed due to a radiologist’s schedule, illness, or vacation while the demographics file was sent upon date of discharge from the treating facility.

**Checklist 19.8: Coding and Billing Interface**

- Interfaces to and from the billing system.
- Data format for export from the sending facility.
- Data format needed for data import of the receiving facility.
- Data to be transmitted (patient demographics, reports, orders, etc.).
- Security of data transmission and related data backup procedures should something interfere with the transmission.

As with any information transfer, varied approaches may be taken to ensure adequate notification is given to confirm that the correct data are received. Other safeguards should also be taken to ensure that the transmission may be re-sent in the event of disruption, and that all data remain intact and available in the event of any dispute.

Radiology billing and coding, although a small component of what an imaging informatics professional needs to know, can prove to be one of the most challenging due to lack of everyday experience in this area. In most institutions, the role of the CIIP will be to ensure that timely and accurate patient demographic and billing information is available to the coding and billing team in the specific electronic format they require. By following these points, the process should be a more reliable and well-planned experience.

**Pearls 19.9**

- Correct coding and billing is an essential piece of the business of radiology and is most often the responsibility of a dedicated team of coders.
- Familiarity with the format of CPT and ICD9 codes is needed for accurate data transfer.
- The RIS, the HIS, and the PACS all contribute elements that are needed for appropriate coding, and these data transfers must be managed individually.
- Security and reliability of data transmission are of extreme importance.
Suggested Reading


Self-Assessment Questions

1. What does MRN stand for? How does it differ from a social security number?
2. What is the difference between CPT and ICD9 codes? Why are two different sets of codes needed?
3. Describe the format of a typical CPT code. Describe the format of a typical ICD9 code.
4. Name five data fields critical to billing and coding of radiologic procedures.
5. Where is the coding team for your radiology department located?
Part V
Strategy and Vision: Preparing for PACS
Associate Editor: David L. Weiss
Chapter 20
Economics of PACS and Related Systems

George H. Bowers

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20.1 Introduction

In this chapter, we will deal with the challenges associated with getting a PACS project approved, paying for it, and then measuring its value to the organization after it is installed. From an economic perspective, PACS is just like any other investment in information technology in healthcare. Because capital dollars are always scarce in healthcare, capital tends to flow to the projects that have made the best business case for why they should be funded. Historically, the business case for investing in information technology in healthcare has been weak and has generally failed to meet the expectations of the organization. Much was promised but what was delivered was not what the organization necessarily valued. In some cases, IT projects were held up to a standard of return on investment that was unrealistic because of the very nature of information technology. In many

Anecdote 20.1: Return on Investment

One particularly cynical CFO said he would only approve a PACS project if the Director of Radiology gave him the names of the people in the film library whose jobs would be eliminated by the system.
cases, organizations expected that by simply investing in new information systems, benefits would magically flow without making changes in the underlying business and clinical processes. Information technology is an expensive tool. How that tool is used will be the source of the benefits. The benefits from investing in IT are often indirect because of the changes in process and workflows.

It has always been a challenge to justify buying a PACS based on film and chemical savings. In the era of replacement PACS, those benefits are no longer on the table. Yet there is an opportunity to make the investment and bring value to the organization. A major investment in any information technology like PACS requires a solid business case that describes the value of the investment to the organization in terms that can be understood and then measured.

### 20.2 Defining “Value” from Information Technology Investments

- Successful healthcare organizations invest resources in opportunities that will return “value” to their organization.
- Value is defined as the results of the investment divided by the cost of the investment.
- Results are the desired outcomes that support the strategic business objectives of the enterprise such as
  - Increased profitability
  - Increased market share
  - Ability to meet regulatory requirements
  - Improvements in health status
  - Improvements in business processes
- Where the results are greater than the cost of the investment, then the value is positive.
- Ideally, the results yield many multiples of the cost, meaning greater value. Where results can be measured in monetary terms, measuring value is relatively straightforward.
- Where the results cannot be measured in comparable terms to the cost of the investment, then measuring value becomes more subjective.
- How does an organization place a value on intangible results such as
  - Improvements in patient safety.
  - Reduction in the time required to diagnose disease.

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**Anecdote 20.2: IT Spending**

IT spending in healthcare has always lagged. In 2003, the banking industry spent $14,764 per employee compared with healthcare at $3,047 (www.itmweb.com/blbenchspn.htm.)
– The fact that these results cannot be measured in dollars does not mean that there has been no value delivered to the organization.

• The key to establishing value from intangible benefits is being able to measure results against a performance benchmark.
  – Benchmarks should be established as a part of the business case for making the investment.
  – Results must be measurable if value is to be determined.
  – When the results are not measurable economically, the comparison of results against costs to determine value is no longer a straight mathematical equation but a logical equation.
  – If the organization makes the investment (cost) and specific results are achieved (results), then the organization has received value.

• Before any investment is made, the organization must understand its performance expectations ahead of time.

• Expected value must be established in the business case as a part of the return on investment analysis.

• In a successful business case, the resulting benefits of the investment need to be linked back to the strategic objectives of the organization.
  – If one of the strategic objectives is to improve patient safety, how will investing in PACS support that objective?
  – How will the organization determine that the investment has performed?

• Making the linkage between the investment and the organization’s perceptions of value is a critical step in moving forward and making sure that the investment is successful.

### 20.3 Return on Investment

#### 20.3.1 ROI Components

Economic decisions about PACS must be broken down into their components in order to get a true sense of the value of the investment. Developing a return on investment model is useful for analyzing costs and benefits and can be especially helpful in identifying a financing model for the investment. The constituent elements in an ROI model include

Further Reading 20.3

• The HIMSS Davies Award was created to recognize excellence in the implementation and use of information technology in healthcare. Davies winners have well-defined business cases. For further reading see: [http://www.himss.org/ASP/davies/index.asp](http://www.himss.org/ASP/davies/index.asp)
• the results (both tangible and intangible)
• the costs of the investment to the organization
• the period of time used to evaluate the investment

Time usually refers to the useful life of the investment. It is a critical component in calculating the rate of return as well as evaluating overall value derived from the results. Matching the time period of the results against the costs is essential in order to get the true value of an investment.

20.3.2 Total Cost of Ownership

In selecting a PACS or other large information system, there are numerous cost components that must be considered in determining the true total cost of ownership over the useful life of the investment (Table 20.1).

Definition 20.4: Turn Key Solution

Some organizations prefer to have a single vendor provide everything required for the PACS. This model is referred to a “turn key.” Even if the vendor is responsible for everything, the vendor needs to provide a breakdown of the costs into the constituent categories.

- Major Categories of Costs
  - **One Time Costs.** These are costs that are paid once over the useful life of the investment. They may only include payments to the system vendor or they may include other one time costs incurred by the institution. Onetime costs are usually capitalized and then amortized over the useful life of the investment. One Time Costs can be further subdivided into outside costs

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### Table 20.1 Cost analysis matrix

<table>
<thead>
<tr>
<th>One Time</th>
<th>Ongoing</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Products</td>
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</tr>
<tr>
<td>Hardware</td>
<td>$</td>
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<tr>
<td>Software</td>
<td>$</td>
</tr>
<tr>
<td>Implementation</td>
<td>$</td>
</tr>
<tr>
<td>Conversion</td>
<td>$</td>
</tr>
<tr>
<td>Training</td>
<td>$</td>
</tr>
<tr>
<td>Project Management</td>
<td>$</td>
</tr>
<tr>
<td>Interfaces</td>
<td>$</td>
</tr>
<tr>
<td>Development/Custom</td>
<td>$</td>
</tr>
<tr>
<td>Maintenance</td>
<td>$</td>
</tr>
<tr>
<td>Other Cost</td>
<td>$</td>
</tr>
<tr>
<td>TOTAL</td>
<td>$</td>
</tr>
</tbody>
</table>

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G.H. Bowers
that are paid to outside vendors, and *inside costs* that are incurred internally by the organization.

- **Recurring Costs.** These costs are incurred as a result of operating the new system. Besides payments to the hardware and software vendors, these also include internal incremental operating costs such as additional staff to support the system.

**Types of Costs**

1. **Hardware.** Hardware includes servers, workstations, monitors, data storage devices, and any electronic required for the operation of the system. While the vendor may be the primary source of hardware, there may be other hardware costs that are overlooked in the analysis. This could include anything ranging from desktop UPS units to replacement components kept as spares.

2. **Software.** This is the cost charged by the vendor for the use of the software for a given period of time. Vendors license software through a number of different methods:
   - *site license*, which enables any number of users at a specified location to be able to access and use the system;
   - *per seat license*, which specifies the maximum number of users who can access the system (this type of license is often qualified by *concurrent* user licenses which places a cap on the total number of users who can be using the system at one time);
   - *per workstation license*, which licenses specific units of hardware rather than users;
   - *volume based license*, which ties the license to a certain range of procedures per year, admissions per year, etc;
   - *size-based license*, which is usually tied to the bed size of the organization or the gross revenue (smaller institutions pay less than large institutions);

   Whichever license method is presented, it is critical to understand any factors which will cause the license fee to increase (or decrease) over time.

3. **Implementation.** These are charges by the vendor for installing the system at your location. Payment of implementation fees is usually tied to specific project milestones during the installation of the system. Implementation fees are sometimes included in the initial software license fees.

4. **Conversion.** Conversion costs are usually incurred with a replacement PACS and can be significant, particularly if there are several years worth of studies to be converted to the new system. These costs cover the effort to take

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**Key Concept 20.5: Trigger Points**

It is critical to understand the *trigger points* for volume-based licenses in order to calculate the total cost of ownership, particularly if growth is expected over the useful life of the investment.
records from one system and convert them to records that can be read by the new system. These costs may include charges to “scrub” the data where records may not reconcile to other systems such as the HIS or RIS. Conversion costs are frequently quoted as a charge per record.

5. **Training.** These costs cover the expenses associated with establishing a level of competency among the users of the system. The majority of training costs are inside costs associated with the time of the staff members who conduct the training and the users who are learning the system. Training takes individuals away from performing their jobs and therefore is a true cost to the organization.

6. **Project Management.** Any PACS implementation project should have a designated project manager. Project management is critical to achieving long term value from a system. This function may be delegated to someone within the organization such as an IT project manager, contracted with the vendor, or purchased from an outside consultant.

7. **Interfaces.** PACS is most effective when it is integrated with the other information technology in the organization. Most PACS vendors include HL7 interfaces to HIS and RIS in their base product at no additional charge. Certain legacy applications may require a custom interface to be developed. In addition to a one-time charge, there may also be an annual maintenance fee for custom interfaces.

8. **Development/Custom.** Most organizations purchase PACS as COTS (Commercial, Off The Shelf). Some organizations may require custom modifications or enhancements to the base product in order to accommodate legacy systems or specific technical architecture requirements. These modifications are usually at an additional cost and may also result in additional annual maintenance fees.

9. **Other Outside Costs.** There are a number of instances where a PACS vendor will require their customers to have another vendor’s software product to provide all of the functionality of the system. Many vendors sublicense workstation software to provide enhanced functionality such as 3D visualization or specific procedural capabilities such as CT angiography or virtual colonoscopy. Many vendors also use commercial database management software for archive management. The cost of these licenses is usually a separate line item in the purchase contract. Many of these third party vendors may have different charges depending on the institution, which may make it worthwhile to look at purchasing the software independently from the main vendor. For example, many large database management software vendors provide discounts to educational institutions. Academic medical centers may qualify for a greater discount than if they purchase the software through the PACS vendor.

10. **Other Inside Costs.** Purchasing PACS may trigger a number of additional expenditures that are directly required to support the project but may be overlooked as indirect costs. Among this type of costs are
- **Renovation costs.** These are costs associated with facility renovations to accommodate new reading workstations, renovations to facilities housing the servers, electrical and/or HVAC modifications.

- **Network infrastructure.** Purchasing a PACS frequently triggers an upgrade to the network infrastructure. These costs include the cost of new network equipment required to handle projected PACS traffic and costs to upgrade wiring such as the network backbone or the cabling to the desktop from the closets.

- **Other Related Purchases.** Organizations frequently buy PACS along with other digital modalities to support going film-less such as CR (Computed Radiography) or DR (Direct Digital Radiography). The costs of these purchases that work hand-in-glove with PACS should be included in the costs for the ROI analysis because it is easier to measure the beneficial results of both investments working together. For example, implementing CR and PACS together replaces film and processing costs. It is not unusual to see as much as a 30% increase in technologist productivity with the implementation of CR with PACS. But it is nearly impossible to precisely measure how much of that increase was a result of the functions provided by PACS and the changes in workflow caused by the CR.

- **On-Going Costs**

Every investment in information technology has an on-going cost component. These costs include vendor maintenance fees, inside support costs, and

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**Key Concept 20.7: Software Maintenance**

*Software maintenance* is usually expressed as a percentage of the list price of the software license. Vendors will often discount the initial licensing fee with the objective of making it up with the software maintenance fees. **It is common for an organization to pay more in maintenance fees over the useful product life than they did for the original license fee.** Software maintenance costs may also increase over time if an inflation adjustment was included in the original contract or another factor based on changes in volumes or size. In performing the ROI analysis, it is critical to understand how these charges are calculated, when they will begin, and under what circumstances they will increase.
equipment replacement costs. It is important to include these costs in an ROI analysis because they can be significant over the useful life of the investment.

1. **Hardware Maintenance Costs.** Most hardware purchased new will have a manufacturer’s warranty for a period of time. At the end of the warranty, the vendor from whom the hardware was acquired (who may or may not be the PACS vendor) will charge a monthly maintenance fee. These fees cover access to hardware support with some guarantees of performance.

2. **Software Maintenance Costs.** Software vendors charge an annual fee for using their product that is supposed to cover the development of software enhancements, product R&D, new releases, and access to vendor support services. Some vendors offer a warranty period before software maintenance charges begin while other vendors begin charging software maintenance upon first productive use of the system.

3. **Other Operating Costs.** Other costs will be incurred over the useful life of the PACS. Some organizations may wish to include these costs as a part of the ROI analysis while other organizations may dismiss them as a cost of doing business. Examples of these costs include:

   - **Support Staff.** A PACS requires imaging informatics professional staff to support its ongoing care and feeding. Taking these costs into consideration is important if they are incremental resources brought on to support the new system. Besides the salary costs, an additional factor for benefits can be included to get a true cost of support staff.

   - **Equipment Replacement/Upgrades.** Overtime, equipment components will fail and require replacement. Other components, such as data storage, will require additions to support the growth in the system. Predicting these costs is an educated guess. Data storage will undoubtedly get cheaper, but storage requirements will undoubtedly increase as the volume of procedures increases and newer modalities are developed. Some reasonable factor should be included in the ROI analysis.

**Calculating Total Cost of Ownership**

The industry standard for evaluating the total cost of ownership for an information technology investment has been five (5) years. Five years was chosen because it was long enough to amortize the costs of the investment against the benefits but still short enough that the organization would not be locked into this system if newer technology developed. In reality, most information systems used in healthcare have a much longer useful life, particularly if the vendor has kept the product current with new releases and system upgrades. Many organizations have expanded that time horizon used in ROI analysis to seven (7) years, particularly when looking at major enterprise wide systems such as CPOE and PACS. The chief benefit of extending the analysis period is that it gives two additional years of benefits to be considered in the equation. Before including the timeframe in the business case, it is important that the finance leadership in an organization buy in on all of the elements to be used in the ROI model.
In preparing the total cost of ownership component of the ROI analysis, one-time and recurring costs should be entered into the model in the year in which the expenditure is likely to occur. At this point, the model shows the cash outflows for the investment by year of ownership. Further adjustments to the model may be made to assume financing the one-time costs over time through operating or capital leases. The time value of the cash will be taken into account when the outflows are matched against the benefits.

**Definitions 20.9**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPOE</td>
<td>Computerized Provider Order Entry</td>
</tr>
<tr>
<td>EMR</td>
<td>Electronic Medical Record</td>
</tr>
<tr>
<td>EHR</td>
<td>Electronic Health Record</td>
</tr>
</tbody>
</table>
20.3.3 Measuring Benefits

At this point, we have established that any IT investment will have benefits that can be measured economically and benefits that will be measured by non-financial metrics. Economically measurable benefits can be subdivided into two more categories:

1. **Hard-dollar benefits.**
2. **Soft-dollar benefits.**

A **hard-dollar benefit** will deliver a measurable savings in costs or an increase in revenue. These are the benefits that CFOs love because they are tangible and can be used to pay back the initial investment. With PACS, savings in film costs and chemicals are examples of hard-dollar benefits. Hard-dollar benefits should be used in calculating the financial return on investment.

**Soft-dollar benefits** are those that can be measured in money but do not necessarily translate into cost savings or revenue increases. For example, if PACS saves an OR technologist 30 minutes a day by not having to search for and hang films, it is possible to take that person’s salary and calculate a dollar benefit associated with that saved half hour per day. But saving half an hour a day is not necessarily going to result in a cost savings to the organization unless the number of staff can be reduced. In a large organization, that might be possible which would then make this a hard-dollar benefit. In other organizations, a direct cost savings might not be possible. This type of benefit is measurable and should be included in the business case because the organization’s management can decide how that extra time will be spent. Soft benefits open the door to improvements in efficiency and effectiveness through improving workflow. Information technology can be the enabler of process redesign and workflow improvements, but directly linking hard-dollar savings may be difficult or impossible.

There are a number of areas where PACS can yield measurable economic benefits. Whether these benefits are

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**Our Experience 20.10:** Cost Justification

Many creative ideas for cost justifying PACS popped up in the early 1990s. One radiology chairman used the following argument to his CFO to justify spending $3.5 million for a new PACS: “Because PACS eliminates lost films, this system could pay for itself if we avoided having to paying just one malpractice judgment where we could not have not otherwise produced the diagnostic films.” The CFO did not buy the justification or the PACS.

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**Key Concept 20.11:** Process Redesign

Technology alone will not improve workflow or yield benefits unless there is **process redesign** to take advantage of the new technology. Automating a poorly designed process tends to highlight the flaws.
soft dollar or hard dollar depends on the individual organization and their ability to translate these benefits into real savings. Almost any potential benefit can be assumed to have some potential financial benefit, but it may require stretching.

<table>
<thead>
<tr>
<th>Checklist 20.12: Economically Measurable Benefits of First-Time PACS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Film and Chemicals</strong></td>
</tr>
<tr>
<td><strong>Film Library Cost</strong></td>
</tr>
<tr>
<td><strong>Productivity</strong></td>
</tr>
<tr>
<td><strong>Report turnaround time</strong></td>
</tr>
<tr>
<td><strong>Lost films</strong></td>
</tr>
<tr>
<td><strong>Electronic access to images</strong></td>
</tr>
<tr>
<td><strong>Increase in volume of procedures</strong></td>
</tr>
<tr>
<td><strong>Improved staff satisfaction</strong></td>
</tr>
</tbody>
</table>

An organization may achieve other benefits from PACS that are unique to it. Benefits may accrue for installing PACS with a new RIS. If imaging equipment is also being upgraded, there may be even more benefits. For example, implementing computed radiography standalone will achieve some benefits, but implemented with PACS, the benefits are exponential. In building a solid business case, the scope may need to be expanded to include these other elements in order to get a true picture of how the organization will be impacted.

To build the business case and ROI analysis, the benefits that the organization thinks are attainable must first be selected. The next critical step in the
process is to establish a baseline that will act as a benchmark for measuring performance. Without this baseline, it will not be possible to measure this benefit. **Baseline benchmarks** that can be established numerically are relatively straightforward. For example, it is very easy for an organization to measure how much it is spending on film, chemicals, and other supplies. It is also easy to measure benefits that are tied to times, volumes, or widgets. Some benefits may require a deliberate effort to establish a baseline. For example, measuring satisfaction of employees or physicians is not always a routine measure. Establishing the baseline may require conducting a “pre-PACS” satisfaction survey.

### Our Experience 20.13: Converting the Film Library

During the implementation of a first PACS, there is a major question of how to deal with all of the films in the film library. There are three main approaches:

1. Digitize all film in the film library.
3. Digitize prior films as required.

Some organizations, like the Medical University of South Carolina, decided to completely digitize their film library when they implemented PACS in the 1990s. Even though the digitization process took a long time, in the end there was no need to maintain a hybrid reading environment. The disadvantage of this approach is that it takes a long time to achieve savings in the film library because these individuals who would not be required post-PACS will still be needed to digitize film.

Maintaining a hybrid reading environment is generally an unsatisfactory approach except for a very short period of time. This approach creates poor reading productivity for the radiologists (and furthermore, they do not like it!).

Many organizations implement an approach where they only digitize prior films as required. This process has the film librarians checking inpatient lists and scheduled outpatients against jackets in the film library. The librarian selects the films to be digitized and loads them into the PACS. The advantage of this approach is that it enables the film library to begin downsizing from the inception of PACS. The downside of this approach is that the prior images might not be available digitally if the patient arrives through the emergency department.

This issue goes away with time. In our experience, within 18 months of PACS going live, the majority of prior images required by the radiologist will be available online.

The next step is to project the benefits that will be achieved over the time period of the investment. It is useful to take each benefit and separately
project the benefits. Benefits should be aggregated into hard-dollar benefits, soft-dollar benefits, and soft benefits, but each should be presented individually with a description of how the benefit will be achieved and the assumptions used.

### 20.3.4 Creating the Financial Return on Investment (ROI) Analysis

The financial ROI analysis compares the total costs of ownership with the sum of the cash savings and inflows resulting from the hard-dollar benefits compared over the measured life of the investment. Table 20.2 shows an example of an ROI analysis.

In Table 20.2, benefits are usually separated into revenue benefits (cash inflows) and cost reductions (cash savings). The first column, “One Time Costs” represents cash outflows at the beginning of the project. The remaining columns represent each of the years in the life of the investment. The total of these items represents the amount of actual dollar benefits that can be expected in each year. Line 13 calculates the present value of these benefits using a

<table>
<thead>
<tr>
<th>Benefits: Revenue</th>
<th>One time</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
<th>Total</th>
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<tr>
<td>Example 1</td>
<td>$ -</td>
<td>$ -</td>
<td>$ -</td>
<td>$ -</td>
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<td>Total revenue</td>
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<td>Example 1</td>
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<td>Example 3</td>
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<td>Example 4</td>
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<td>$ -</td>
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<tr>
<td>Total hard cost reduction</td>
<td>$ -</td>
<td>$ -</td>
<td>$ -</td>
<td>$ -</td>
<td>$ -</td>
<td>$ -</td>
<td>$ -</td>
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<tr>
<td>Total benefits:</td>
<td>$ -</td>
<td>$ -</td>
<td>$ -</td>
<td>$ -</td>
<td>$ -</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td>Present value of benefits:</td>
<td>$ -</td>
<td>$ -</td>
<td>$ -</td>
<td>$ -</td>
<td>$ -</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td>Total cost of ownership</td>
<td>$ -</td>
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<td>$ -</td>
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<td>$ -</td>
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<td>From Table 20.1</td>
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reasonable interest rate determined by finance. The net difference between the
cash inflows and the cash outflows is simply the benefits minus the costs in each
of the years. The cumulative cashflow is a running total of the cash inflows and
outflows in each year. In most IT projects, the cumulative cashflow is negative
for a number of years before it becomes positive.

20.4 Completing the Business Case

The assembled business case should include the following information:

- Description of the project including the scope, the time period, and the
  organizational resources being impacted.
- The relationship of the project to the strategic objectives of the organization
  including how this project fits in with other global IT initiatives.
- Summary of the expected benefits of the project and why it is recommended.
- Detailed presentation of the benefits including metrics, baseline, and expected
  outcomes for each benefit: hard-dollar, soft-dollar, and soft benefit.
- ROI analysis.

A successful business case will present compelling reasons why this project is
important to the organization. It is broader in scope than just a financial ROI
analysis. Ideally, the financial ROI analysis will show a positive payback, but
even if it does not, a good business case will provide compelling reasons why this
project should be undertaken.

20.5 Financing PACS and Other IT Expenditures

In developing the business case for a project, it may be determined that there
needs to be a way of financing the project so that not all of the money is being
spent upfront while waiting for benefits to accrue. There are a number of ways
in which information technology expenditures are financed and accounted for
by organizations.

- **Capital Investment**
  - Cash generated from operations
  - Pay for the majority of the IT investment up front
  - Requires amortization of the investment over the projected lifespan of the
    investment
  - Least costly alternative over lifespan of the investment
  - May not be the most efficient use of capital if other sources are available

- **Capital Lease**
  - Financing from third party over the majority of the life of the investment
  - Appears on the balance sheet as an asset and requires amortization
  - Requirements:
- Lease life exceeds 75% of the life of the asset; and/or,
- Transfer of ownership at the end of the lease, usually with a “bargain” price; and/or,
- PV (present value) of lease payments exceeds 90% of the FMV (fair market value) of the asset;
  - Little flexibility for adjustment during the life of the asset
  - More expensive than buying the investment outright

**Operating Lease**
- Lease period usually shorter than the expected life of the investment
- Ability to cancel or upgrade during the term of the lease
  - Can take advantage of technology advances
  - Remaining term rolled into new lease
- Appears as an operating expense and not on the balance sheet (although some lenders/bond covenants require disclosure of operating leases)
- Usually more expensive than capital leases
- Buying organization is responsible for system operations

**Application Service Provider/Remote Hosting (ASP)**
- Similar to an operating lease but includes additional services.
- Operating expense over a fixed period of time, usually 5–7 years.
- Turn-key - all inclusive.
- Includes off-site processing, back-up, disaster recovery, etc.
- Puts the onus on the vendor to install upgrades and maintain the system.
- Usually provided directly by the vendor, but sometimes with a third party.
- More expensive over the term of the agreement than outright purchase.
- May be charged on a volume basis (“per click”) or a fixed monthly fee.
- Requires less IT organizational infrastructure investment.
- Attractive to organizations with limited capital and limited IT capabilities.

**Third-Party Financing**
- Leasing companies
- Healthcare equipment vendors
  - Usually requires commitment to buy other equipment from them.
  - Not as readily available since the subprime mortgage crisis.

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**Further Reading 20.14: ASP**

Further Reading 20.15


Further Reading 20.16


Pearls 20.17

- Value is defined as the results of an investment divided by the cost.
- It is critical to be able to measure the performance of an investment, even when the results are not defined in dollars and cents.
- An investment in information technology needs a business case that shows the linkage to the organization’s strategic objectives and describes the expected results from the investment.
- In order to measure return on investment (ROI), it is critical to understand all of the cost components over the life of the investment, not just the up-front costs.
- Making an investment in information technology may be worthwhile even if there is not a measurable return on investment; the value of the investment may come from subjective measures such as improved patient safety, faster diagnosis time, or improved clinician satisfaction.

Suggested Reading


Self-Assessment Questions

1. Which of the following are examples of results that support the strategic business objectives of the enterprise?
   a. Increased profitability
   b. Increased market share
   c. Ability to meet regulatory requirements
   d. Improvements in health status
   e. All of the above

2. Value is defined as
   a. The financial return of an investment divided by the cost of the investment
   b. The results of an investment divided by the cost of the investment
   c. The percentage financial return over the life of the investment
   d. The cash flow of the investment over the life of the investment
   e. None of the above

3. Which of the following software license costs would increase if the number of procedures performed per year increases?
   a. Per seat license
   b. Site license
   c. Per workstation license
   d. Volume-based license
   e. Size-based license

4. Which of the following is frequently overlooked or underestimated in calculating the total cost of ownership?
   a. Training
   b. Hardware maintenance
   c. Ongoing software maintenance
   d. Renovation expenses
   e. Interest on bank loans

5. The usual period of time for calculating total cost of ownership is
   a. Two to three years
   b. Two to five years
   c. Ten years
   d. Five or seven years
   e. Fifteen years

6. Which of the following are hard-dollar savings from PACS?
   a. Cost of film and chemicals
   b. Faster report turnaround
c. Improved physician satisfaction
d. Increased patient safety
e. None of the above

7. Investments in information technology will not yield improvements unless
   a. Business processes are redesigned to take advantage of the technology.
   b. Additional money is invested each year.
   c. The organization hires more than one PACS administrator.
   d. The CFO sees a tangible financial return.
   e. None of the above.

8. The least costly way to finance PACS over its useful life is
   a. Pay cash (capital)
   b. Operating lease
   c. Capital lease
   d. Application service provider
   e. Vendor financing
Chapter 21
PACS Readiness

Steven C. Horii

21.1 Introduction

There are numerous reasons for making a change from a film-based radiology department or practice to an electronic one. However, for any facility to make such a change, it is important first to ask a fundamental question, “Why do we want to make a change to PACS?” If the radiology group has difficulty answering this question, it is either too early to make this decision, or the group needs to do further study.

Because of the complexity of the decision to change to PACS, it is difficult in this short chapter to provide a comprehensive list of reasons for making the change. However, it may be useful to know some reasons that are not good ones. Commonly, though improperly considered, reasons for changing to PACS include

- It is the trend.
- We have extra capital to spend.
- We expect to save a lot of money by making the change.
- Our imaging equipment vendor will give us a good deal on a PACS.
- A PACS will solve all our workflow problems.
The decision to change to PACS-based operation is complex, but is usually driven by a combination of factors, including

- Digital imaging workload exceeds film-based capacity.
- Film-based workflow for digital imaging systems is inefficient.
- Demands for near real-time radiology cannot be met with film-based operation.
- Teleradiology for expanded practice or off-hours coverage is nearly impossible with film.

### Checklist 21.2: Initial Questions for PACS Readiness

- Why are we doing this?
- What are our goals and expectations?
- Do we have support for this change from the practice members and/or hospital administration?

### Hypothetical Scenario 21.1: Cost Reduction as a Reason for PACS

Despite the great emphasis on reducing costs in healthcare, it is difficult to justify a PACS purely on cost reduction grounds. Initial operations with PACS may be higher than for film, though there are estimates of from 3 to 7 years for “break even.”

### 21.2 Assessment

The next major question to be answered is “Where are we now?” Answering this is not as simple as it may sound as it involves a thorough study of both the radiology department and its interaction with the rest of the healthcare facility. While the process of creating a detailed **functional diagram and specification** of the radiology department is done after a PACS readiness decision is made, a first step should be an assessment of the major interactions between the radiology and the other departments. This can be useful in determining radiology report and image retrieval rates by the referring physicians.

#### 21.2.1 Items to Assess

##### 21.2.1.1 Workload

Much of the following can be assembled from various sources and put into spreadsheets. This will make editing, analysis, comparison, and charting of data simpler.
How many studies of what kinds? These data are usually available from departmental logs, billing records, or a radiology information system (RIS).

Number of reports generated in various time periods (per day, per week, etc.). Note variations during each time period (e.g., by time of day, day of week, month of year).

Estimate of growth rate; extrapolate or project from existing data, trends, and any known expansion of services or facilities. Radiology business managers usually do this sort of study regularly.

If a multisite practice, prepare the above for each site.

Are studies read where they are performed or are films (images) moved to a central reading location? Is this expected to change with PACS? If so, how will this change? This is important in assessing where images are moved so network capacity can be estimated.

21.2.1.2 Workflow

The “where are we now?” question also has a component of workflow. There are technical definitions of workflow since there is software that can take formal workflow descriptions and turn them into operational software. However, in an informal sense, workflow is a description of what you do.

As an example, work a radiologist does is “read an x-ray.” That certainly describes work, but not much about what happens to accomplish that. Suppose for this example that there is a specific work item, in this case, dictating and signing a report. A workflow description of this would try to break this down into steps:

- The radiologist has viewed the films and is ready to dictate.
- She or he picks up the microphone of the dictation system and begins by dictating the patient name, identifier, history, date, and examination type.
- The radiologist dictates the report.
- When done, the radiologist dictates, “end dictation on...” again, usually giving the name of the patient.
- The transcriptionist listens to the dictated report and types it (typically into a computer system, even in film-based operations).
- The radiologist reviews the transcribed report (either electronically or on paper) and if there are no corrections.
- The radiologist signs the report (electronically or physically).

Note that each of these steps could be further broken down into much finer detail and likely varies in such detail from practice to practice, but for the sort of workflow analysis intended for PACS readiness, this level of detail is usually more than sufficient. A specific version of this would describe the dictation...
system, signing method, and would also include the error correction steps (omitted here for simplicity).

A simple way to think of workflow steps – each step has

- some sort of **input**,  
- **a task performed** on the input, and  
- some sort of **output** based on the task performed.

The reader is encouraged to look at the “read an X-ray” example above and determine the input, task, and output of each of the steps.

Methods for workflow analysis:

There are several methods that can be used to perform this workflow assessment process. These are typically based on a more detailed examination of what the practice does currently. Typical methods include

- **Follow something** – In this method, you follow various things to see what happens to them and where they go. You could, for example, pretend to be a patient (or follow an actual patient if they give their permission) and record all the places they go, what happens to them at each place, and who is involved at each location from when the patient comes in to when they leave. You then follow other personnel (technologists, radiologists, file room clerks, referring physicians, etc.) and “things” (films, reports, mobile equipment, etc.) using a similar process.

- **Brainstorm** – This requires less manual labor, but does require that you meet with the people involved. You gather those who work in your practice and ask them to describe in detail what they do. Again, keep in mind that you want to know what they do, when they do it, who is involved, where the person or thing they work with came from and where the person or thing is going. This method has the disadvantage of potentially missing steps; you can minimize this by having several people who do the same task describe their workflow.

- **Hire someone** – This is certainly a viable option, but keep in mind two things: (a) the cost and (b) that you want to be sure that all the information you want collected is included in the description of what your expert will do.

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21.2.1.3 Imaging Equipment

Since a PACS will need to acquire images from your imaging equipment, an inventory of the equipment is also a must for PACS readiness. This is an inventory process, but has a couple of elements not typical for a simple listing. In the list of equipment you create, you want to include at least an estimate of the **number of studies** done per day on that equipment and if it is slated to be replaced when the PACS is implemented.
Our Experience 21.5: A Short Workflow Story

In preparing to implement PACS in our Ultrasound Section, we did some time-and-motion studies of our sonographers. We found that the time they spent interacting with the RIS was between 3 and 5 minutes per patient. For our daily volume, that amount of time could mean an additional examination done per sonographer per day. Even after PACS, though the RIS interaction time has been reduced, a follow-up study showed that the time had decreased to just under a minute per patient. The main reason for this is that the sonographers still have to interact with the RIS to complete examinations. The reduction in time resulted from DICOM modality worklist that automated loading of patient information into the ultrasound machines. We still do not have DICOM Performed Procedure Step that would allow the information that an examination is complete to flow back to the RIS from the ultrasound machine or PACS.

Our Experience 21.6: A “Follow the Film” Result

One thing we discovered when we did a “follow the film” study was that many films did not go to the film library after reading, but went elsewhere, at least temporarily. We had a film multiviewer installed in the Medical Intensive Care Unit (MICU) and film library clerks would take the day’s MICU films, once read, and load them on the MICU multiviewer. They were then available for the MICU physicians to review. We had an RIS in place, so reports were available electronically and an RIS terminal was installed near the multiviewer. Every morning, one of the radiologists would go to the MICU and do imaging rounds with the MICU physicians. Since we knew about all these tasks, when it came time to switch to PACS, we made sure to include a method and equipment that would allow us to continue these functions. If we had not considered this, we would have forced the MICU physicians to come to radiology to see the images, something that would adversely impact their workflow.

Key Lessons Learned:

- Films do not always go where you predict.
- A PACS has to support image distribution to these diverse locations.
- Failing to account for this can adversely impact workflow of your referring physicians and others.
Definitions 21.9: DICOM Ready and DICOM Conformant

**DICOM ready**: The equipment does not include a DICOM interface, but one is available as an option. **Caution**: Though equipment may have been purchased as “DICOM ready,” if it is more than a few years old, the option may no longer be available from the manufacturer.

**DICOM conformant**: The equipment includes a DICOM interface and a conformance statement is available that describes the particulars of the DICOM implementation.

Key Concept 21.8: Analog or Digital?

A major question in assessing PACS readiness is determining how much of the equipment you have is digital. Specifically, whether or not the radiographic systems are analog film-based or digital. “Digital” in this case also includes digital radiographic systems that are configured to print analog film.

If you have digital radiographic systems, you are likely more ready for PACS than if you have analog radiographic equipment. However, some digital radiographic machines require a replacement of the x-ray generator and not just the addition of a digital detector. This can mean a higher budget for transition and planning for architectural, demolition, and construction costs.

Checklist 21.7: Equipment Inventory

- Equipment type (e.g., “CT”)
- Equipment name and model number
- Short description (e.g., “64-slice CT”)
- Equipment location
- Daily examination volume on equipment
- When purchased
- If and when to be replaced
- DICOM ready or DICOM conformant?
- DICOM conformance statement on file?
- Applicable software versions
- Options installed, if any
- Date(s) of last inspection(s) or calibration (may include both electrical safety and radiation physics)

The inventory lists should be prepared as spreadsheets; this makes incorporation into an RFP easier and also allows for electronic transmission to vendors. This checklist should be considered a minimum; your PACS committee may add other items depending on particular circumstances (e.g., “equipment to be moved” if you are expanding your facility and will be adding exam room space).
21.2.1.4 Information Systems: The RIS

Some vendors supply integrated systems that provide both RIS and PACS functionality. This has distinct advantages; for example, a single database and much smoother integrated operation than interfaced RIS and PACS.

**Key Concept 21.10: Inventory and the RIS**

The most critical question to be answered regarding an “inventory” of equipment is whether or not you have an existing radiology information system (RIS). The RIS is so important to PACS operation that, for places that do not have either system, many would advise purchasing an RIS first and getting it installed and running prior to acquiring a PACS.

**Our Experience 21.11: Combined RIS/PACS**

During an unfortunate unplanned downtime, we recently discovered a major disadvantage of an integrated RIS–PACS. If the systems are truly integrated, when you lose the functionality of one system, you lose both. In an interfaced RIS and PACS, if either system goes down, the other can usually keep running, albeit in a slower or more limited fashion. In our situation, the RIS drives the PACS, and our speech recognition system is part of the RIS. When the RIS crashed unexpectedly, we were still able to acquire and view images, though it took phone calls and paper lists to find what studies had to be read. Since the speech recognition system is integrated with the RIS, we had no dictation capability (we long ago gave up conventional dictation) for most of the department. A few sections were still using an older, separate speech recognition system and that was functioning, but without the RIS, reports could only be dictated and saved as text files. When the RIS came back up, we had to cut and paste those text files into the reports. This was a cumbersome and lengthy process. Those without any dictation system wound up working extra hours to get all the backlog of studies dictated.

**Key Lesson Learned:**

- Integrated systems need to be highly reliable and highly available.

If you have an RIS, you should plan to discuss all the aspects of your RIS with potential PACS vendors. Key questions include the following:

- **Does the RIS support an interface that can provide patient, scheduling, and examination information (type of examination, order or accession numbers, requesting physician, patient history)?**
- **Can the PACS utilize such an interface?**
Does your RIS support the Integrating the Healthcare Enterprise (IHE) profiles you will need?

Is an RIS–PACS interface one way (RIS to PACS) or bi-directional? This is important because some workflow can be greatly streamlined if information can go from the PACS back to the RIS (for example, information that an examination has been completed – this may originate at the imaging equipment and be sent to the PACS, but it ultimately has to go back to the RIS to “close” the request for that examination).

### 21.2.1.5 IHE Profiles

- The IHE effort was started by the RSNA and Health Information Management Systems Society (HIMSS) with a goal of using existing standards (DICOM and HL7) to support communication between PACS and other healthcare information systems.
- IHE has defined a set of “profiles,” which are descriptions of the ways the standards are used in certain clinical scenarios.
- The IHE profiles have been demonstrated at the RSNA and HIMSS (and other) meetings to show that they work and can be implemented. Unfortunately, adoption in products has not been as fast as the IHE committees, or end users, would like.

**Further Reading 21.12: IHE**

- The best reference for the IHE profiles is online: [www.ihe.net](http://www.ihe.net). Also, on the IHE website, a document titled, “IHE Radiology User’s Handbook” can be downloaded at no cost and should be required reading. It describes the various profiles and what they mean and, most importantly, sample language for including in RFPs and purchase contracts so vendors can be required to support the profiles.

**Definition 21.13: HL7**

HL7 is a standard ubiquitous in the nonPACS healthcare information system world. This includes most hospital and radiology information systems. Like DICOM, HL7 is a standard, though quite different from DICOM. It is aimed chiefly at sending messages between systems to carry nonimage information. Most interfaces to hospital and radiology information systems use HL7. HL7 used to be an acronym, standing for “health level 7” and referring to the application layer of a communications model. However, HL7 is now a name, not an acronym. To communicate between an RIS and PACS, HL7 messages from the RIS will likely have to be “translated” into DICOM and from DICOM into HL7 if information has to go back to the RIS from the PACS. This translation is often done with a computer known as a “broker.”
21.2.1.6 Other Information Systems: Advanced Visualization

- The availability of thin-section CT, volumetric MR acquisition, 3D and 4D ultrasound, digital mammography, and PET-CT or SPECT-CT means that many facilities have **specific workstations** to make use of these 3D imaging techniques.
- In a non-PACS environment, these will be standalone systems, though they are usually connected by a local network to the imaging equipment.
- The value for PACS readiness assessment is that many thin client advanced visualization systems are, in **effect, small PACS**.
- Some means of making the processed images available on a general PACS is important.

**Definitions 21.14: Thick and Thin Clients**

A thick client is a software application that completely “takes over” the operation of a workstation computer. While other applications may be run, the thick client typically has to be minimized or paused to allow such operation. All of the application’s power is in the thick client software; servers typically provide image data only.

A thin client is a software application that gains most of its power from a server. This is very much the way a web browser works. The content of a web page as well as any interactive tools need only minimal software on the workstation; the server handles the tasks the user requests.

21.2.1.7 Key Considerations if You Have Advanced Visualization Systems

- Whether or not the system needs **proprietary image data** from the imaging equipment;
- If a proposed PACS can communicate the proprietary images without generating errors;
- If the advanced visualization system provides **storage for the source images** and, if not, it can retrieve the images needed from the PACS (if in DICOM or proprietary formats);
- What **network bandwidth** is needed for both communication of source images from imaging equipment and (for thin client systems) for using the server from remote clients; and
- If the advanced visualization system supports the **IHE post-processing workflow (PWF)** profile so that users can access studies in a familiar manner (e.g., from a worklist) and output resulting processed images to a PACS with correct information so that they may be accessed by PACS users.

21.2.1.8 Information Systems: Teleradiology and On-Call Support

If you have a system that is used to send some images between imaging centers and your main office, from outlying hospitals to a central facility, or to
radiologists at home for on-call support, you have part of a PACS. The chief difference between these systems and a general PACS is that these systems do not usually include a storage component and may not include all imaging systems. They also use wide area network (WAN) communications technology usually purchased as a service from telecommunications providers.

Having such systems in use provides several advantages for facilities. These include

- information technology support personnel familiar with image communications;
- existing interfaces from imaging equipment, often DICOM;
- users are familiar with interpreting studies on workstations; and
- experience using telecommunications provider WAN services.

Challenges for these systems and PACS include

- interfacing them to a new PACS;
- if you decide not to continue with these systems, replacing their functions in a new PACS; and
- if you do decide to keep these systems, having them interoperate with the PACS. That is, the automation features of the PACS should operate with these systems.

21.2.1.9 Information Systems: miniPACS

Even closer to having a PACS is operating a “miniPACS.” These are typically in ultrasound and nuclear imaging as they both have in common the need for specialty functions not provided by many PACS workstations.

21.2.1.10 Key Considerations for miniPACS in PACS Readiness

- The situation for PACS readiness with miniPACS that you may have is similar to that for teleradiology systems.
- It is less likely that a general PACS vendor will be able to replace an ultrasound or nuclear imaging miniPACS completely.
- The interfacing and interoperation requirements are similar to those for teleradiology if a decision is made to keep the miniPACS rather than replace them with a general PACS.
- The experience with miniPACS is even better preparation for transition to a general PACS than is familiarity with teleradiology systems.
- A miniPACS is directed at supporting one imaging technique, so the multiple requirements of a general PACS may not be met in part or at all by these miniPACS.
- Your IT support people and users will have experience with the problems of communications, interfacing, displays, and storage that general PACS also have.
21.2.1.11 Information Systems: Desktop Computing – Why Is This Important for PACS Readiness?

- Even in a practice with digital imaging but still printing film, one likely use of computers is on the desktops of radiologists, administrators, and technologists.
- The use of electronic mail and web browsing is ubiquitous and computers are usually provided to meet those needs.
- A practice without a web presence is “invisible” to many potential patients and referring physicians, so even a practice without a general PACS will advertise its capabilities on the World Wide Web.
- The chief importance of desktop computing and experience with web applications for PACS readiness is the increasing use of thin clients to support PACS. Some vendor offerings for PACS are completely web-based.
- Even if a vendor does not have a thin client general PACS, most vendors have a web-based “enterprise” system that provides web-based access to the general PACS.
- If you have PCs installed throughout your facility, you potentially have a distribution system that covers a wide area and can help solve the problem of how you provide images to referring physicians once you eliminate film.
- An inventory of PCs, their types, locations, and basic software should be part of your PACS readiness preparation.

21.2.1.12 IT Infrastructure: Communications Network – Key Questions and Considerations for PACS Readiness

- Do you, or do you not, have a communications network in place?
- If you do, what is the bandwidth and expandability?
- Most PACS will require large bandwidth, though that bandwidth may vary across different parts of the PACS.
- Imaging equipment to PACS may be in the gigabit/second range; PACS to workstations more often uses 100 megabit/second network connections.
- The network design will depend on how the PACS is designed.
  - Web-based and other thin-client PACS will likely need overall wider bandwidth since these systems tend to move images to workstations as they are requested rather than cache them in workstation storage.
  - The hardware and physical configuration of your present network are key planning points. Many of the older cable installations (often called the “cable plant”) may use cables that cannot support current wider bandwidth communications.
  - For these reasons, a “where are we” assessment should include a description of your local area network.
Ideally, this will consist of a diagram of the network as well as a detailed list of the various electronics elements that are in it, the locations of network wiring closets, and the placement of network jacks.

Key Concept 21.15: The Alphabet Soup of Networks

“Category n” cabling typically refers to bundles of twisted pairs of wire. Generally, the higher the category number, the higher speed the cable will support. Most cabling now being installed is Category 5, 5e, or 6. These are sometimes abbreviated “Cat5,” etc. If Cat5 cable is carefully installed, if connectors are applied to specification, and if the lengths of the cable do not exceed specified limits, the cables can be used for gigabit/second networking.

Ethernet is the most common local area network. It has a shorthand for describing speed. For example, “100Base-TX” is 100 megabit/second over twisted-pair cable. Gigabit Ethernet is 1000 Base-TX. There are sometimes other numbers or letters following the “T” that define twisted-pair cable types. Other letters in place of the “T” indicate other types of cable. For example, -FX, -SX, and -BX refer to optical cable.

21.2.2 Personnel

- A PACS readiness evaluation should include a review of personnel.
- Vendors are likely to recommend a specific personnel complement, but there are things a PACS committee can do to help determine if there are sufficient employees to begin a PACS transition.
- If you have an existing miniPACS, teleradiology system, or a RIS, it is likely you have a manager of those systems; potentially someone who can serve as your PACS manager.
- Keeping up with all the imaging equipment connected to the PACS, the vendor updates and upgrades of those systems, and troubleshooting the PACS interfaces may dictate that you have a separate “modality manager.”
- If you are a multifacility practice, you will either need to have a dedicated operations person devoted to PACS at each facility, or an individual who takes care of the PACS and other information systems.
- Having personnel to help end users in person is extremely important. Users are likely to have enough history of frustration with telephone support for various things that forcing them to do this for PACS will lessen user willingness to use the system.
21.3 Change Management

A change from film-based, or disparate digital systems, to an integrated PACS is a major change for any medical imaging practice. A part of readiness assessment is to examine the problems that will drive change management. Unfortunately, change management is often not fully considered, or is assumed to be so obvious as to be trivial. A failure to consider change management principles is an invitation to a much more difficult process than would otherwise be the case.

There is much literature on change management, but the principles applied to PACS readiness analysis include the following:

Our Experience 21.17: On-Site Engineering

As an academic institution, we have not only legacy information systems, but also legacy workflow. While it has been possible to adapt much of what we do to newer information systems, we have not found that commercial systems have been able to provide all the functions we need. Many of these are small projects, but difficult for vendors to take on because they are unique to our hospital. We have programmers who both manage the RIS and can create the database reports needed by administration and researchers. With the changing requirements for insurance reimbursement, being able to generate ad hoc reports and modify standard ones has been a necessary capability. We also have a systems engineer familiar with the various interfaces and databases that the information systems use. He has been able to write software that can carry out many of the functions not covered by gaps in the vendor-provided systems. We refer to such in-house developed code as “spackleware” (since it fills gaps, not because it has anything to do with enamelware of the same name).
Key Concept 21.18: FUD

What you may notice among employees as you begin to discuss a change to PACS is “FUD” – fear, uncertainty, and doubt. Typical fear responses are, “My job will go away!” Uncertainty can be expressed by, “I’m not sure I can learn this.” Finally, there is doubt, “There is no way I can get my job done using this!” A goal of change management is to prevent FUD and to try to make sure that the various scenarios expressed by FUD are not realized.

- From the very inception of the idea to make the change to PACS, communicate the idea, the goals, and the processes involved as widely as possible. Keep communication frequent, regular, and informative.
- Involve those affected (as described earlier).
- Be realistic about expectations and goals; do not oversell the project.

21.3.1 Training Issues

Because the change to PACS from film-based operation or a transition to full PACS from dedicated digital systems will affect nearly everyone in your facility, readiness assessment should include a consideration of how you will carry out the training needed.

Main considerations for training:

- Details of training will depend on the specific PACS implemented.
- Training plans can be straightforward to develop but very difficult to implement.
- Managing to get all the people who need to learn new ways of working trained is made difficult by competing complex schedules.
- A PACS readiness assessment should include determining what facilities are available since it is very difficult to train in clinical areas.
- For the readiness phase, determining what space and facilities are available for training in advance of the RFP preparation means that you can tell the vendor exactly what to expect when they respond to your RFP.
- Since it can be very difficult to teach all employees their new work methods simultaneously, an approach that is commonly used is to “train the trainers.”

21.3.2 Record Keeping and History

An unfortunately forgotten aspect of implementing systems is to maintain a history of them. For many critical systems outside of, and some within, healthcare, detailed hardware and operational histories are the norm.
Aircraft are a good example. For airplanes, recordkeeping is mandated by the Federal Aviation Administration.

Physicists keep records of dosimetry for equipment that exposes patients to ionizing radiation.

Hospital biomedical engineers have logs of equipment tests for equipment electrical safety.

**21.3.2.1 Important Aspects of Maintaining Systems’ Histories**

- Without good records, it can be difficult to determine if your vendor is adhering to the terms of the service agreement. The information may exist in telephone or e-mail records, but it is not readily available.
- Good records can help you spot troublesome trends and institute preventive measures. For example, if your records show excessive downtime for a particular workstation, you could replace that workstation and do (or have the vendor do) detailed troubleshooting on the removed hardware.
- Historical records can help you with quality assurance requirements. You can more easily determine if a program you institute has beneficial or detrimental effects.

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**Key Concept 21.19: Training the Trainers**

Each section of the department would designate someone who would be among the first people trained. They might also get training beyond the basic level, including training at a vendor’s facility. When the PACS transition is starting, these individuals then act as additional teachers. They also have a great advantage over the vendor personnel in that they will have the knowledge of how your department or practice works and they will know most of the people who work in your department. Once the system is fully operational, these “superusers” also act as a first line of defense in problem solving and will usually have sufficient administrative privileges on the systems to correct some errors, set up new users, and help document user complaints and system bugs. Because this may be extra work, a readiness review of personnel should also include the potential for an additional title and pay for those who make the effort to be superusers. Since it can take time to establish new job categories and pay differentials, it is a good idea to include this in the readiness work.

Besides additional pay, becoming a superuser can, for those individuals so motivated, be a career advancement step. They may have the background, or acquire it, to move from superuser to a supervisory role, and potentially to management. The availability of certification programs in imaging informatics makes this a potentially attractive path for some of your personnel.
21.3.3 Getting Help

As mentioned at the beginning of this Chapter, a decision made early in the process should be whether or not an external consultant is needed. There are two major reasons to decide this. First, the workflow of a department or facility may be so ingrained in the behavior of personnel that it is difficult to get a comprehensive view of the processes. Second, if you make decisions and plans and then retain a consultant, you will spend considerable time “bringing the consultant up to speed.”

21.3.3.1 Main Decision Points for Getting External Help

- An external view of your operations is a way to avoid missing things. An alternative is to have representatives on your PACS committee review workflow they are not familiar with.
- A review of information technology can be difficult with internal personnel because of the technical knowledge required. Members of your committee who are responsible for IT of another department are likely to have the

Our Experience 21.20: Recordkeeping

From the very outset of determining PACS readiness, my recommendation is to establish a policy of recording history and documenting events. This can be initially assigned to one person, but when a transition to PACS is made, the task may be too difficult for one individual. Keeping good records is extremely important in academic facilities. For example, if a researcher decides to study reductions in report turnaround time when speech recognition replaces conventional transcription, it is usually easy enough to determine the date when the transition was made. However, if there has been a software or hardware change and the date and nature of that change are not recorded, any effects on radiologist performance may become a confounding variable in the study.

A PACS committee should have the status of a true “deliberative association” and as such, minutes should be kept and reviewed as part of procedure. Minutes may seem to be a drudge, but having them can be a time-saver when a change is made from the readiness assessment function to drafting a PACS RFP. It can avoid having to re-discuss decisions already made, or provide some background about why a particular alternative was chosen. If an external consultant is later retained, the minutes of PACS committee meetings can be a way to acquaint the consultant with goals, limitations, and decisions made.
technical knowledge and be removed enough from your IT operations to provide an unbiased overview of them.

- You should find an independent consultant. That is, the consultant should not be an employee of one of the PACS vendors, nor have any significant financial position with them.
- Due diligence is important; check the references of any potential consultant. Especially valuable is the opinion of someone whom you know well at a facility for which the consultant has worked.

### 21.4 Summary

A transition from film-based (or partial PACS) operation to a comprehensive PACS should be preceded by a readiness review and assessment process. A similar process should be used when changing PACS vendors as the reasons for changing are likely to require that you re-examine your workflow and goals. The basic principle of a readiness review is to understand as completely as possible why and how you currently do things and how you expect a PACS to change this. Once you have established these basics, the rest is filling in the various details.

**Pearls 21.21**

- Make sure that you are switching from film to PACS for the right reasons.
- A thorough assessment of the current status of the department will allow for a smooth transition to PACS.
- Understanding departmental workflow is key to understanding the needs of the department and the patients and physicians whom the department serves.
- Existing modalities and information systems can make the transition easy, or make it hard.
- Proper change management is the key to user acceptance of PACS.
- The right external consultant can make the transition a lot smoother.

**Suggested Reading**


Self-Assessment Questions

1. List several good reasons for transitioning to PACS. Then list several bad reasons for doing so.

2. Which of the following are important elements to assess in planning for a PACS transition?
   a. Estimated rate of growth for the department
   b. Current state of imaging equipment
   c. Current personnel
   d. Existing RIS capabilities
   e. All of the above

3. Which of the following is NOT an element of workload assessment?
   a. Number of studies performed
   b. Estimate of growth rate
   c. RIS compatibility
   d. Peak times for report generation

4. Which of the following individuals does NOT require a workflow assessment in preparation for the transition to PACS?
   a. The radiologists
   b. The technologists
   c. The support personnel (transport, file room)
   d. The patients
   e. They ALL require workflow assessment

5. What is the difference between DICOM ready and DICOM conformant?

6. Data exchanged between the RIS and the PACS would most likely use which standard for data formatting?
   a. HL7
   b. DICOM
   c. TCP/IP
   d. IMAP

7. Advantages of pre-trained “superusers” include all of the following EXCEPT
   a. Potential career advancement for the superuser
   b. Knowledge of internal dynamics of the department
   c. Knowledge of key departmental personnel
   d. Reduced workload for dedicated support personnel
   e. Reduced cost of training
Chapter 22
Choosing a Vendor

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22.1 PACS: Making a Decision Based on Needs

The advent of picture archiving and communication systems (PACS) allowed storage and distribution of digital images and patient information throughout the healthcare enterprise. PACS enables easy availability of digital images on virtually all clinical workstations throughout the healthcare institution, which helps to improve the workflow, report turnaround time, productivity, and clinical care. A careful selection of the type of PACS solution based on the institution’s demands, workflow, and infrastructure is vital. Finding a suitable vendor that can satisfy these requirements is equally important.

Further Reading 22.1: Choosing a Vendor

- The SIIM Expert Hotline Archive (www.siimweb.org/expert hotline) has many articles with recommendations for choosing a PACS vendor.
22.2 Developing an Appropriate Business Plan

- Assess existing practice in detail and develop a needs assessment.
- Consider requirements of all stakeholders:
  - Radiologists
  - Technologists
  - Radiology administrators
  - Clinician specialists – surgeons, orthopedists, emergency department, and physicians
  - Other referring clinicians
  - Information technology (IT) department
- Review requirements for archiving and viewing images from other departments:
  - Cardiology
  - Obstetrics
  - Visible light images – endoscopy, dermatology, pathology

A thorough needs assessment should include both an operational (for example, workflow) and a technical analysis (for example, existing infrastructure, storage and network requirements, HIS/RIS interface).

- Business plan and cost–benefit analysis.
- Incorporate return on investment (ROI) analysis. Include estimated costs for initial and ongoing expenses versus expected cost savings.
- Factors to consider:
  - cost of film and film handling
  - potential liabilities
  - improved workflow
  - decreased workload
  - improve patient care

Further Reading 22.2


- Once the decision for PACS implementation is made, considerable planning is needed before selecting, purchasing, or implementing PACS. Development of a strategic business plan should survey the following:
- Facility infrastructure and existing resources
- The views of the administration and critical stakeholders
- Educating administrators and critical stakeholders by communicating the key benefits of PACS is a key step in this process. This involves collecting details on various factors such as
  - Site or sites where images are acquired, the primary interpretation sites for various subspecialties, and the clinical review sites.
  - Detailed list of all imaging modalities including manufacturer’s names, model, and software versions. This is important in order to identify the upgrades needed to allow a successful integration with PACS.
- Available financial resources for implementation.
- Additional resources needed:
  - Personnel including technical staff
  - Available space for installation
  - Hardware and software requirements
- Software applications such as RIS, scheduling, dictation software such as speech recognition, EMR, or HIS, and imaging modalities that will be integrated with the PACS.
- Critical stakeholders who will be affected by PACS implementation.
- Existing technical staffing data for imaging modalities and available statistics on throughput in order to project the effect of PACS.
- Current and predicted radiologists, reading room locations, number of subspecialties to estimate the number of primary interpretation workstations needed.
- Current and predicted exam volume data to estimate the archive requirements.
- Current and predicted operating room viewing, intensive care units, emergency room, clinics, and physician offices to determine the enterprise requirements.
- The next step is to determine a clear set of goals and key objectives for PACS implementation, for example, the expected percentage increase in the productivity using PACS, expected savings on film-based expenditure, or expected time for a complete or nearly complete conversion to a digital environment.
- A PACS team should be assembled, which will be accountable for the project. The team should be composed of people with the right expertise and those who will primarily be affected by

Further Reading 22.3: PACS Preparedness
- Chapter 21, PACS Readiness, has more in-depth information about analyzing your department in preparation for the transition to PACS.
Our Experience 22.4: PACS Implementation

A comprehensive PACS implementation at our institution began in late 1995 and was completed over 4 years with subsequent deployments of additional workstations.

The payback period for the PACS deployed was 48.8 months. In the year of payback, the cumulative profitability of the increased PACS volume contributed 124% of the cumulative capital investment while the cumulative film savings contributed 79% of the capital cost.

In terms of increased productivity, at 90% implementation, PACS implementation was associated with an estimated $29 \pm 4\%$ increase in the professional productivity (work RVUs) and a $63 \pm 5\%$ gain in technical productivity (RVUs).

Also, with 90% PACS implementation, there was a decrease in the mean interval between completion of the examination and dictation of the preliminary reports and mean time takes for final signing of the report after completion of the exam by 16 hours from the initial values of 22 and 31 hours, respectively.

the PACS implementation. The PACs team should include the following:

- Radiologists familiar with clinical and workflow issues
- Technologist supervisors with similar expertise
- IT staff members
- Financial experts

For an enterprise-level PACS, clinical stakeholders (cardiology, endoscopy, obstetrics) with expertise should be consulted. In the absence of required expertise in specific clinical areas, an external consultant is helpful to facilitate interdepartmental communication.

- The PACS team should define the principal criteria for evaluating the different vendors and include these in the RFP.

22.3 Contents of an Effective Request for Proposal (RFP)

- Before selecting a particular PACS solution, an institution should strongly consider issuing a request for proposal (RFP).
- The main objectives of an RFP are
  - to provide the vendor with an overview of the enterprise.
  - to provide a detailed description of the specifications with the intent of including the vendor’s response in the final contract.
  - to obligate the vendor to deliver per the requirements specified.
– to solicit responses that facilitate comparison among the vendors particularly with respect to the issues identified as the selection criteria.

• A well-written RFP should minimally include the following sections.

### 22.3.1 Goals and Objectives of the Radiology Department and the Healthcare Enterprise

Which include expectations for

• extent and time frame for digital transformation
• departmental and enterprise productivity improvements

#### Our Experience 22.5: Time Frame

The reasonable time frames for small, medium, and large institutions are 3, 6, and 12 months, respectively, if the site is initially film-based, with at least half this time being adoption by the clinicians (which is frequently never accomplished in its entirety).

This time also depends on where the site is with its modalities. For instance, acquisition of modalities like digital radiography and digital mammography often and incorporation of older equipment (e.g., nuclear medicine, US) that are not DICOM compliant do not turn over as frequently as CT and MR. This often lags PACS implementation by months or even years.

### 22.3.2 General Information About the Healthcare Enterprise

• Single site or multiple sites across a larger healthcare enterprise
• Number of sites
• Types and number of specialties
• Locations of the key departments
• Patient population
• Inpatient and outpatient imaging volume at each site
• Number of inpatient beds at each site
• Plans for expansion of the facilities
• Business strategies of the enterprise as a whole

### 22.3.3 Operational and Workflow Information About Radiology and Other Departments with Access to PACS

• Workflow
  – Current workflow
• Patient registration to exam scheduling
• Ordering and performance of the study
• Interpretation of the examination by the radiologists
• Report generation
  – Specific workflow:
    • For individual sites in a multisite organization
    • For each imaging modality at each site
• Workload for professional staffing and exam volume information:
  – Number and location of imaging sites.
  – Number of imaging modalities at each site.
  – Exam volume by modality at each site.
  – Inpatient versus outpatient mix.
  – Number and location of interpretation sites.
  – Subspecialties at each site.
  – Number of radiologists, including number of staff members, fellows, and residents.
  – Number of examinations reported in a day.
  – Number of radiologists reading simultaneously.
  – Division of work within the department.
  – Departments such as the emergency department and intensive care units, which may require high resolution, high luminescence monitors (medical-grade monitors) similar to those deployed at diagnostic workstations.
  – Other consumers of medical imaging such as referring physicians, radiotherapy, surgeons, orthopedists, and remote sites requiring images to be transmitted from PACS (for example, teleradiology operations).
  – Projections of volume changes.

22.3.4 Technical and Hardware Requirements of the Organization

• Acquisition of images: List the imaging modalities including vendors with model numbers, date of purchase, software version, and DICOM compliance for each modality.

• Archiving and storage of images:
  – Estimate and explicitly specify requirements for online cache storage capacity as well long-term persistent storage.

Key Concept 22.6: PACS Functional Requirements
System functionality for the end user is a critical aspect of PACS and therefore, this section in the RFP should be detailed and well thought out.
- For an enterprise SAN (storage area network) infrastructure provide specifications and request integration with the enterprise SAN.
- Preferred method of storage of prior exams from different options such as
  - Lossy compression in online storage versus uncompressed or lossless compressed images in long-term storage.
  - Presence of priors versus no priors on online storage.
  - Specify if long-term storage will be online or will act as nearline storage from which the images are prefetched.
  - Specify time frame during which images must be immediately available online.
  - Requirements for backup and disaster recovery.
  - Preferred storage vendor (if different from the PACS vendor) in order to enable integration.
- **Retrieving images and interpretation**
  - **Workstation Requirements**
    - Number of workstations.
    - Type of the required monitors (e.g., medical or commercial grade, resolution, single/dual/quad configuration).
  - **Software Functionality**
    User interface – worklists, queries, report displays, image displays, paging, stack mode, hanging protocols, prior report display, image manipulation (e.g., window/level, zoom, pan/scroll, magnifying glass measurements, region of interest, annotation).
    - Advanced visualization options from the PACS vendor and need for integration with a third-party software (e.g., MIP, MPR, volume rendering, PET/CT fusion, CT colonography, nuclear medicine), which depends on any existing third-party software or hardware and workflow.
    - Responses should include both native PACS vendor solutions and third-party integration.
  - **Web distribution**
    - Requirements for a web-enabled application to allow distribution of images for clinical review across the healthcare enterprise.
    - Specification for areas with access to PACS images such as technologists, IT support staff, and film librarians.

**Key Concept 22.7: RFP Construction**

- Provide detailed specifications of the institution’s software functionality and hardware performance requirements for both primary interpretation and clinical review.
- Request that vendors specify whether they can provide these features and describe any available alternatives.
- **Integration requirements**
  - Specify need for integration of existing radiology information system (RIS), scheduling (if separate from the RIS), speech recognition, and EMR with PACS.
  - Request vendor for specifications, prior experience, and pricing for the interfaces linking the RIS to PACS.

- **Data Management**
  - Specify the requirements for patient demographic and image data management which is typically done with commercially available database management systems (e.g., Oracle, MS/SQL, Sybase).
  - Request the specification of data management systems and provide a detailed description of any redundancy features of this system component, as it can be a single point of failure in any PACS system.
  - Request that the vendor describe any tools provided to correct patient and exam data as required.

- **Image Management**
  - Request for description of support for image management features such as
    - Image import
    - Image compression
    - Automated archiving
    - Automatic purging of images from cache storage
    - Routing of images to third-party workstations or systems
    - DICOM functions (such as DICOM query/retrieve, DICOM copy)

- **Networking Infrastructure**
  - Existing networking infrastructure across the enterprise with available local area networks (LAN) and wide area networks (WAN) interconnecting all sites should be described.
  - Request for assessment of suitability of the existing infrastructure and need for upgrades.
  - Demand in writing that the agreed-upon final network within the enterprise is adequate.
  - Define the minimum acceptable performance requirements for several measurable scenarios based upon various representative image sets. For example, the vendor should specify the maximum time taken by the PACS to fully display a 200 image CT study from cached storage as well as total time to import the study from the modality and display on the workstation.
  - For jukebox storage archive, specify maximum time for an ad hoc query of a defined data set.

- **Timeline for Installation and Implementation Responsibilities**
  - PACS implementation typically requires a multiphase approach.
  - State the planned time line for each phase.
– Outline of the enterprise’s expectations, priorities, and objectives for each phase.
– Request for details on the implementation responsibilities and personnel involved, including minimum qualifications, and time spent on the site and costs associated with implementation.

**Training Requirements**
– Request details for various user classes such as radiologists, technologists, referring physicians, system administrators.
– Request the training setting, hours, number of sessions, and required reference materials.

**Maintenance and Support**
Request details of support and maintenance commitments the vendor is expected to offer during the implementation and planning including
– the vendor’s support strategy
– staffing
– nearest sales and service office
– expected uptime
– service response times for remote and onsite support
– software release schedule
– installation of software updates

**Financial Terms**
– Provide an itemized (line item) pricing form to facilitate comparison of the bids among the vendors solicited.
– Request details of the contract
  • With regards to pricing, length of the contract offered, and payments.
  • Include details on all components of the system and services offered (e.g., software, hardware, technical costs, labor costs, upgrades, system integration, installation, training, and extended maintenance services).

**Warranties**
– Describe expected warranty coverage and duration along with upgrades provided during this period.
– Request detailed description of what the warranty includes.
– Demand the vendor the same uptime guarantees and service response times as the support committed to in the maintenance and support section.
– Demand that the PACS offered must remain compliant with all applicable laws and regulations, including FDA.

**Data Security**
– Description for security and authentication supported by the system and compliance with HIPAA standards and regulations.
– Request details on backup and disaster recovery techniques.

• **Other additional information and response form**
  – Ask vendor for a summary of their experience: years in business, number of sites, references.
  – Provide details on
    • The selection process along with evaluation criteria and procedure.
    • Confidentiality issues.
    • Contact information for clarifications and questions.

• Provide a concise response form to help in direct comparison between the vendors and facilitate the selection process.

### Further Reading 22.9: RFP


### 22.4 Review of Responses to RFP

Written responses can help the buyer compare the merits of each system and make appropriate selections of the solution most suitable for their facility.
**Step-by-Step 22.10: Reviewing Responses to RFP**

1. The PACS selection team should short list the vendors to a manageable number (about 4–6 vendors) selecting those who appear to be most suitable for their requirements.
2. The RFP should be sent out to these vendors giving them a firm response date (generally less than 8 weeks to respond).
3. The responses to the RFP should be summarized and tabulated for evaluation. All discrepancies or ambiguities should be clarified with the vendor.
4. For evaluation of the responses, each criterion being judged should be first weighted by importance using consensus of the members of the selection committee.
5. Each vendor should be scored for each criterion and these scores weighted based on the importance of the category being analyzed.
6. The scoring should be based on the responses to the RFP as well as prior knowledge of the vendors.
7. The totals of the weighted scores should then be calculated for each vendor.
8. Based on the evaluation, the vendors should be narrowed down to 2–3 preferred and alternative vendors for manageable contract negotiations.

**22.5 Site Visits**

- Selection committee should schedule one or more site visits at locations where the PACS under consideration are already being used.
- Schedule site visits close to each other in time in order to ensure better comparison.
- The buyer does not necessarily have to go to the sites chosen by the vendor but can specify other sites, with the system version that the institution is intending to purchase, and similar workflows, business requirements, and IT infrastructure (i.e., RIS, HIS, voice recognition).
- The review team including radiologists, IT staff, radiology administrators, technologists, and referring physicians should attend the site visits in order to identify technical and operational issues.

**Key Concept 22.11: Site Visits**

Site visits are an important step in selecting a vendor as the team can get a feedback from those who have already implemented the proposed solution. By providing the opportunity to observe the system in action, a comprehensive site visit can help the team discover and anticipate many potential issues that may impact a successful implementation.
For an enterprise-level PACS, clinicians’ opinion is important; however, since site visit teams are limited (6–8 people), only the key players (clinicians with expertise in the field) should be included in the site visits. Often the Chief Medical Information Officer represents the clinician in the absence of local expertise amongst the clinicians.

- Site visits should be planned carefully.
  - A specific site visit agenda should be established.
  - A list of questions and evaluation criteria should be provided to the target site prior to each site visit to optimize the time spent during the site visit.
  - The individual members of the review team should focus on their own area of expertise, scheduling time to talk to their peers at the site during the visit.
  - The team should ensure that, at some point, they can speak with key stakeholders without the vendor being present.

**Further Reading 22.12: Site Visits**


**Checklist 22.13: Site Visit – Sample Questions**

- Radiologist should evaluate the workstation and observe different users for time taken and steps involved for actions such as
  - Open a new case
  - View images
  - Manipulating images, annotating, saving
  - Access prior reports and images
  - Retrieving prior exams for comparison

- Technologists should evaluate the networking and steps involved in sending completed exams to PACS

- IT staff should ask for demonstration of a merge, name change and other alterations made on images

- Administration should assess workflow impact of PACS

**22.6 Negotiation of Terms and Conditions**

- **Negotiating the contract**

  To obtain the best possible contract terms, it is generally helpful to proceed with negotiation with two or more vendors with regards to
  - Price
  - System options
- Hardware
- Software upgrades
- Software licensing
- Service contracts

- **Consider payment terms and budgeting**
  - Including associated costs such as
    - Implementation
    - Maintenance
    - Software licenses
    - Interface customization fees
    - Other factors such as loss of time and productivity during implementation
  - Consider several payment options such as traditional capital purchase, lease, application service provider (ASP), where pricing is typically based on the annual exam volume.
  - The decision between the different options usually depends on the financial resources at the given institution.

**Definition 22.14: ASP**

Application service provider (ASP) is a fiscal model for PACS in which the vendor owns, operates, and supports the PACS software. This minimizes support costs but provides no ownership investment.

**Key Concept 22.15: Different Payment Options Include:**

- Traditional capital purchase: needs substantial capital investments, which may negatively impact cash flow. Ownership of equipment bears the risk of technological obsolescence but it allows complete ownership and flexibility.
- Capital and/or operational lease: needs less initial investments on software or hardware and has steady predictable costs.
- Software only option: needs less initial costs as the vendor markup on hardware may be more expensive when compared to other sources. However, institution needs to have the expertise and resources to buy, support, and maintain the hardware.
- Other options like capital purchase of equipment with leasing the software.

- It is more important that at the time of negotiation one must factor in
  - Initial costs.
  - Maintenance: maintenance costs, version changing costs, and replacement costs.
- Operational costs: cost per exam (user must carefully define an exam to offset any confusion and surcharges), costs with fluctuation of exams per year, fluctuations with training of staff due to changes in the version of software or hardware.

Pearls 22.16
- Determine if you need PACS. If so what type of PACS?
- Develop a need’s assessment and strategic PACS business plan.
- Assemble a PACS review committee.
- Prepare a suitable RFP with objectives and goals of PACS stated explicitly, general information about the enterprise and departments utilizing PACS, and a detailed list of requirements and specifications.
- Distribute the RFP to the vendors being considered with an expected response time.
- Review the responses to the RFP by weighing each category and scoring the responses to narrow the field to two or three preferred and alternative vendor.
- Perform comprehensive site visits.
- Negotiate service contracts and decide payment terms and budgeting.

Self-Assessment Questions

1. What is the first step in selection of a vendor?
   a. Developing a strategic business plan
   b. Writing an RFP
   c. Negotiating the contract
   d. Site visits
   e. Deciding payment options

2. How many vendors should be selected by the PACS team to send out the RFPs?
   a. 1–3
   b. 2–4
   c. 4–6
   d. 8–10
   e. 10–15

3. Who is not a stakeholder for PACS implementation?
   a. Radiologists
   b. Technologists
   c. Clinicians
d. Nurses

e. IT staff

4. For an enterprise-level PACS, generally clinicians are a part of the site visit team
   a. Always true – clinicians must always attend visits.
   b. True to certain extent – experts in different divisions may attend or
      limited to Chief Medical in-charge Officer as the number of persons
      visiting sites is limited.
   c. False – consultants replace the clinicians in all visits as the number of
      people visiting sites is limited.
   d. False to certain extent – clinicians’ demands are minimal when compared
      to radiologists.
   e. Vendor decides if clinicians must attend or not.

5. What is not true about site visits?
   a. Location is always decided by the vendor
   b. The review team can include radiologists and clinicians
   c. One or more site visits should be made
   d. Different visits should be close to each other
   e. A specific site visit agenda should be established

6. What is the correct order for the following steps?
   1. The responses to the RFP should be summarized and tabulated for
      evaluation.
   2. The RFP should be sent out to the vendors giving them a firm response
      date.
   3. Each vendor should be scored for each criterion and these scores weighted
      based on the importance of the category being analyzed.
   4. The PACS selection team should short list 4–6 vendors selecting those
      who appear to be most suitable for their requirements.
      a. 4, 2, 1, 3
      b. 1, 2, 3, 4
      c. 2, 1, 3, 4
      d. 2, 4, 1, 3
      e. 2, 3, 1, 4

7. How much time should be given to the vendors to respond to the RFP?
   a. Less than 16 weeks
   b. Less than 8 weeks
   c. Less than 2 weeks
   d. They can take as much time, as long as they address all the questions in
      the RFP
   e. Less than 4 weeks
Chapter 23
Acceptance Testing

Gary S. Norton

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23.1 Introduction

The picture archive and communication system (PACS) acceptance test (AT) serves as an evaluation of PACS performance, identifying deficiencies, and the availability of the system. It can be used to certify contract compliance and payment milestones. It validates the interfaces to a facility’s information systems and radiographic modalities and checks the configuration and calibration of the PACS components. The AT is a technical evaluation of the system and demonstrates the clinical readiness for patient care. Additionally, the AT sets the baseline for a facility’s quality control (QC) program that will monitor the PACS in the future.

Our Experience 23.1: Defining Requirements

The best time to define AT requirements is in the request for proposal that a vendor responds to or during the contract negotiation. It is possible (but more difficult) to test against the vendor’s published specifications and claims about their system. That said, it is important for the vendor and customer to agree to the test protocol and work together for a successful AT.
Consider that film-based radiology has been evolving since the 1890s. We have had over 100 years of education and practice to apply to our equipment QC checks. PACS is less than 20 years old and has forced us to change how we think about the QC. “In the old days,” the technologist used a sensitometer to create a sensitometric strip that we ran through our processors to check the speed, contrast, and gross fog. These data were documented daily using a processor control chart to prove that our film processor was functioning as expected. (Film-based mammography programs require sensitometric monitoring of film processors.) When the processor failed to meet the tolerance limits that had been defined, the processor was cleaned, new chemistry was added, and a new baseline was established. In today’s world, an AT establishes the PACS baseline.

While QC checks in the analog environment were primarily performed by the medical physicists and the technologists, the membership of the AT team can include, but is not limited to, radiologists, the PACS Administrator, biomedical maintenance engineers, information systems representative, and PACS vendor representatives.

23.2 Interfaces and Modalities

The “C” in PACS stands for communication. To function properly a PACS must communicate with the other information systems that are used in a radiology department as well as the radiographic modalities that capture the images. In the digital world, all the orders, images, and reports are electronic information that is transmitted across a network. This section will discuss testing of the communication interfaces between information systems and from these systems to modalities.

23.2.1 System Integration and Interfaces

- In most PACS implementations, the radiology information system (RIS) is the primary source of patient demographic and examination information.
A robust, secure network connection between the RIS and the PACS is paramount; a PACS will not work efficiently without it.

The RIS/PACS connection may be through a digital imaging and communications in medicine (DICOM) broker that translates between the health level 7 (HL7) information in RIS and the DICOM information in PACS. The PACS may also communicate directly with the facility’s healthcare information system (HIS).

Each information system vendor will publish an HL7 conformance statement that will define, to the data element level, information that can be shared between systems. Similarly, the PACS and modalities vendors will each publish a DICOM conformance statement that defines their data elements.

The PACS may also communicate with separate billing systems, dictation systems, transcription systems, or speech recognition (SR) systems using HL7.

Some facilities may use interface engines to handle the messages between these systems and the PACS, and the interfaces may be unidirectional (one way) or bi-directional (two way).

It does not matter how many systems communicate with each other. The overall system throughput for a patient’s examination from the time of order to archive must be tested to ensure that the data have not changed.

As part of the AT project and to understand the interaction of the information at your facility, it is suggested that you map your PACS configuration and all the systems that touch it prior to beginning AT. Figure 23.1 is an example of the information flow around a PACS (C. Head, personal communication, 2007).

### 23.2.2 Modality Integration

- DICOM is the key! Each modality vendor will have a slightly different approach to how they implement the DICOM standard.
- DICOM connections between the modalities and the PACS or information systems are made of three elements: (1) IP address, (2) application entity (AE) title, and (3) port number.

#### Our Experience 23.6

It is important to make the AE title unique for each device and meaningful for your facility. Later, when you are trying to track an error, an AE title like “XMC-US01” is more useful than “650879.”
- Some modalities are completely DICOM ready when purchased, and most modalities will have DICOM store and DICOM print capabilities as part of their basic installation package. However, DICOM modality worklist (DMWL) is usually a separate purchase option in the vendor’s proposal. Depending on the age of the equipment, most modalities can be upgraded to query for a DMWL.
• Non-DICOM modalities or modalities that have partial DICOM capabilities, but cannot be upgraded to do DMWL, can be connected to the PACS with a third-party interface box. The interface box acts like a modality. It can query for a DMWL and then do a video capture (screen scrape) or cine capture from the modality’s console screen. Some modalities may be able to DICOM store to the interface box and the interface box can query for a DMWL and update the exam prior to sending it to the PACS.

• Film digitizers act like any other modality connected to the PACS and can query a DMWL and then DICOM store the scanned films to the PACS, so they can be tested in a similar fashion.

• Laser film printers have been used with digital modalities for several years. The PACS implementation should not adversely affect the modality to printer connection. Printing an image from the modality, then sending the image to the PACS, printing the same image again, and then comparing the quality of the films, is a good way to evaluate a laser film printer. Remember that laser film printers can have look-up tables (LUT) for each connection, so a LUT may need to be added for the PACS.

• Both the system integration and modality interfaces can be tested using thread tests. Thread testing allows the overall system to be evaluated for integrated functionality and throughput.

• Thread tests use clinical scenarios to evaluate the information and imaging stream from acquisition to display, printing, reporting, and archive. Thread testing can be tuned to specifically follow the steps of a facility’s information workflow and how a PACS interacts with that workflow.

Checklist 23.7: Minimum DMWL Data Elements
• Patient name
• Patient ID
• Accession number
• Patient’s date of birth
• Patient’s sex
• Exam requested
• Modality type

Definition 23.8: Thread Test
Once each module in a complex system has been individually tested, sample data are passed from module to module to ensure that they link up appropriately. This is called a thread test. The passage of data should mirror true clinical workflow as closely as possible.

Further Reading 23.9: Thread Tests
### Step-by-Step 23.10: Thread Tests

<table>
<thead>
<tr>
<th>Testing step</th>
<th>Variations and comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Register a test patient in the HIS and verify that the patient data are available in the RIS.</td>
<td>- There may be some network latency at each step in the test. Do not expect the information to appear instantaneously.</td>
</tr>
<tr>
<td>- Enter a test order for a CT head on the test patient in the RIS. Verify that the patient and exam data are present on the CT scanner console’s DICOM modality worklist (DMWL).</td>
<td>- Order entry can be done in the HIS for inpatients and the RIS for outpatients. The patient’s name, DOB, sex, MRN, the exam ordered, and the unique accession number are the minimum data elements to be passed.</td>
</tr>
<tr>
<td>- Select the test patient and test order from the CT scanner console, verify that the data elements map correctly into the scanner’s fields, and capture the CT head protocol using phantom.</td>
<td>- The examination requested may map directly into the CT console or the technologist may have to select the correct procedure from the CT’s predefined protocols.</td>
</tr>
<tr>
<td>- Post-process the test CT head examination. Send the exam to the PACS.</td>
<td>- Some PACS may require a QC step, at a technologist’s PACS workstation, to validate that the examination is complete, and/or to place the exam in a “to be read” status, and/or to scan paperwork to be viewed with the images. The technologist may have to enter exam charges into the RIS or the exam complete message in the PACS may trigger the DICOM modality performed procedure step (MPPS) to send the exam complete message to the RIS so the exam can be billed automatically.</td>
</tr>
<tr>
<td>- The test patient and the completed exam should appear on the radiologist’s “to be read” worklist.</td>
<td>- The worklist may be the “CT to be read” worklist or a predefined sub-set: “CT heads to be read,” depending on the site’s preferences.</td>
</tr>
<tr>
<td>- The exam should display as a CT head preset. Any historical exams on the test patient and/or dictated reports should also display with the un-interpreted new exam images.</td>
<td>- The radiologists should work with the vendor’s application specialist to establish a display protocol for each exam type.</td>
</tr>
<tr>
<td>- There should be an indication on the radiologist’s PACS desktop that an interfaced dictation system or voice recognition system is ready to receive the radiologist’s dictation. Enter a test dictation and notify the transcriptionist that the dictation is present.</td>
<td>- The indication may be a dictation window displaying the test exam’s accession number. This functionality requires an interface between the PACS and the reporting system.</td>
</tr>
<tr>
<td>- The transcriptionist will select the test patient/test exam from the transcription system’s worklist</td>
<td>- For conventional dictation, the radiologist’s dictation may be placed in a wave file in the transcription system.</td>
</tr>
</tbody>
</table>
PACS Component Testing

Getting the patient and examination data from the information systems and the digital image data from the radiographic modalities to display, is basically the same process, no matter which PACS vendor is used. The digital environment

<table>
<thead>
<tr>
<th>Testing step</th>
<th>Variations and comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>The transcriptionist listens to the dictation and types the report. The report is sent back to the radiologist for verification.</td>
<td></td>
</tr>
<tr>
<td>Some PACS do not support this functionality; the preliminary report may only be available in the RIS.</td>
<td></td>
</tr>
<tr>
<td>Separate billing interfaces should be checked to verify that the report verification drops the interpretation charge.</td>
<td></td>
</tr>
<tr>
<td>Some PACS have separate web viewing applications. Verify that the images and completed report are available via the web application.</td>
<td></td>
</tr>
<tr>
<td>There may be some system latency in the archival process. Exams may not immediately move to the long-term or redundant archive.</td>
<td></td>
</tr>
</tbody>
</table>

- After the transcription is complete, verify that the preliminary report is available with the images in the PACS.
- The radiologist will verify the preliminary report in the RIS.
- Verify that the completed report is available at a clinical workstation concurrent with the images.
- Have the vendor or system administrator log into each archival location to verify that the test patient’s examination and report is available.

Checklist 23.11: Modalities Connected to the PACS

<table>
<thead>
<tr>
<th>Modality</th>
<th>Number of units</th>
<th>Testing complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computed radiography (CR)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radiographic/fluoroscopic (RF)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portable radiographic/fluoroscopic (C-Arm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct radiography (DR)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angiography (XA)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computerized axial tomography (CT)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultrasound (US)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnetic resonance imaging (MR)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nuclear medicine (NM)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary capture devices (film digitizers, post-processing workstations)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bone densitometry (DEXA)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digital mammography (MAMMO)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

23.3 PACS Component Testing

Getting the patient and examination data from the information systems and the digital image data from the radiographic modalities to display, is basically the same process, no matter which PACS vendor is used. The digital environment
of PACS has allowed more efficient archive scenarios and enabled image archiving to multiple sites so that off-site disaster recovery storage is an increasingly common option.

### 23.3.1 Image Storage and Archive

- The primary purpose of a PACS image archive is to provide a secure place for the images and attending information to be stored and accessed. To properly test a PACS image archive, the system storage architecture will have to be established prior to testing. Most PACS image archive systems can be divided into three levels of storage:
  1. **Short-term storage (STS)** for recently acquired examinations awaiting interpretation, examinations that are complete but have not “aged” to the point where they are removed from the STS, and pulled or prefetched exams that were retrieved from the next level of storage to be reviewed or compared to a recently acquired examination. Examinations in STS can be quickly retrieved for display.
  2. **Long-term archive (LTA)** is where all examinations are stored for historical record. Display speeds from the LTA may be slower than the STS. (Typically, each examination is written to the LTA immediately after it is written to the STS.)
  3. **Redundant or disaster recovery (DR)** archive is a long-term archive that is maintained separately from the LTA. The DR may be located across campus, across town or out-of-state. Examinations may not be written immediately to the DR but may be queued to be written at pre-defined times.

### Step-by-Step 23.12: Testing the Archives

<table>
<thead>
<tr>
<th>Testing step</th>
<th>Variations and comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Process and acquire an examination on a test patient at a modality in the normal manner and then send it to the PACS.</td>
<td>• Archive testing will require system administrator or vendor level access privileges. If possible check and record the file size of the examination and the number of images being sent from the modality.</td>
</tr>
<tr>
<td>• Sign into a diagnostic workstation and verify that the exam is on the exams pending interpretation worklist. Display the examination and save specific annotations and window/level settings to several images in the examination.</td>
<td>• Check and record the file size of the examination and the number of images. (The archive process may require the examination to be read and/or placed in complete status.) Make note of the annotations and window/level settings made to the examination.</td>
</tr>
</tbody>
</table>

(Continued)
It may not be possible to delete or remove examinations from the DR archive because it is never allowed to delete or remove archived examinations. That said, the DR archive should mirror the LTA. Therefore, removing the DR archive’s connection to the LTA, then adding examinations to the LTA should cause the examinations to be queued for archive when the DR archive connection is re-established.

<table>
<thead>
<tr>
<th>Testing step</th>
<th>Variations and comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>• At the PACS administrator workstation, access the STS and verify that the examination on the test patient is present in the STS.</td>
<td>• Check and record the file size of the examination and the number of images.</td>
</tr>
<tr>
<td>• Access the LTA and verify that the examination on the test patient is present.</td>
<td>• Check and record the file size of the examination and the number of images. (Compression algorithms will affect the file size. If the compression algorithm is 2:1, then the file size should be approximately half the original file size. Verify the presence of compression algorithms and the amount of compression used.)</td>
</tr>
<tr>
<td>• Access the DR archive and verify that the test examination on the test patient is present.</td>
<td>• Check and record the file size of the examination and the number of images. (Archiving to the DR may happen at specific times or immediately. The compression algorithm on the DR may be a different than the LTA.)</td>
</tr>
<tr>
<td>• Go the HIS/RIS and change the test patient’s middle name. Verify that the name change on the test patient migrates through all the systems, so that the STS, LTA, and DR have updated the test patient’s name.</td>
<td>• Verify that the LTA will accept and process the ADT and ORM/ORU messages from the RIS/HIS the same way as the PACS will.</td>
</tr>
<tr>
<td>• Have the PACS administrator delete or “age” the test examination from the STS. Verify that the test examination is no longer on the STS and verify that it is on the LTA.</td>
<td>• The PACS vendor’s representative may have to perform this step.</td>
</tr>
<tr>
<td>• Go to a PACS workstation, select the test patient, and fetch the test examination from the LTA. Verify that the annotations and window/level settings saved to the examination are present.</td>
<td>• Check and record the file size of the examination and the number of images. A lossless compression algorithm should allow the test examination's file size to be restored to its original size. You may want to measure the time to display and verify that it meets your requirements and the vendor’s specifications.</td>
</tr>
</tbody>
</table>
23.3.2 Workstation Functionality

- The basic image manipulation functions of PACS workstations are virtually the same across vendors. Every vendor will allow a user to window/level, flip/rotate, zoom, invert video, and annotate an image.
- A workstation’s functionality can be set to a user’s preference. Depending on the vendor, each different function can be configured and disabled within the user’s profile. Testing a workstation’s functionality is done to ensure that each of the functions is available.
- In addition to the image manipulation functions, historic examination prefetching/autorouting and default display protocols must be checked.

Key Concept 23.14: PACS Differences

Even though user interface functions may be similar, this does not imply that all PACS are the same. Ease of use of these tools is a major differentiator in end-user satisfaction.
<table>
<thead>
<tr>
<th>Testing step</th>
<th>Variations and comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verify that the following are available for the user:</td>
<td>The cursor should move across all screens of the workstation.</td>
</tr>
<tr>
<td>• Move the cursor across multiple monitors.</td>
<td>The user should be able to window/level a single image or all images in an examination.</td>
</tr>
<tr>
<td>• Window/level all and individual images</td>
<td>The user should be able to move/roam the image, increase the zoom, inverse video, and window/level inside the digital magnifying glass.</td>
</tr>
<tr>
<td>• Digital magnifying glass</td>
<td></td>
</tr>
<tr>
<td>• Horizontal flip, vertical flip, and sequential 90 degrees rotation of an image</td>
<td></td>
</tr>
<tr>
<td>• Inverse video</td>
<td></td>
</tr>
<tr>
<td>• Image roam</td>
<td></td>
</tr>
<tr>
<td>• Zoom</td>
<td></td>
</tr>
<tr>
<td>• View CT and MR scout w/slice position indicators</td>
<td></td>
</tr>
<tr>
<td>• View CTs and MRs in stack mode.</td>
<td></td>
</tr>
<tr>
<td>• Display Hounsfield units and statistics</td>
<td></td>
</tr>
<tr>
<td>• Text annotation</td>
<td></td>
</tr>
<tr>
<td>• Image identification</td>
<td></td>
</tr>
<tr>
<td>• Undo last keystroke</td>
<td></td>
</tr>
<tr>
<td>• Save</td>
<td></td>
</tr>
<tr>
<td>• View full image header information</td>
<td></td>
</tr>
<tr>
<td>• Stack</td>
<td></td>
</tr>
<tr>
<td>• Cine</td>
<td></td>
</tr>
<tr>
<td>• Multiplanar reformatting</td>
<td></td>
</tr>
<tr>
<td>Verify that point-to-point measurements are available (metric and inches).</td>
<td>To test this function, measure an object of known size and make sure metrics are correct.</td>
</tr>
<tr>
<td>Verify that the workstation supports angle measurement.</td>
<td></td>
</tr>
<tr>
<td>Verify that the workstation supports area measurement.</td>
<td></td>
</tr>
<tr>
<td>Verify that the workstation supports perimeter measurement of objects.</td>
<td></td>
</tr>
<tr>
<td>Verify that a user can define and save image display protocols.</td>
<td></td>
</tr>
<tr>
<td>Verify that the display protocol allows a user to define image presentation order/number of images on screen.</td>
<td></td>
</tr>
<tr>
<td>Verify that the display protocol can be modality specific.</td>
<td></td>
</tr>
</tbody>
</table>
23.3.3 PACS Monitor Testing

- The American College of Radiology (ACR) and the American Association of Physicist in Medicine (AAPM) have recommended a set of standard testing to be done on display devices used for diagnostic imaging.
- There are primarily two types of PACS monitors in use today cathode ray tubes (CRT) and liquid crystal displays (LCD). Most PACS vendors are no longer selling CRT monitors and the installed base of CRTs are aging out of the PACS inventory, so this section will focus on LCD monitors.
- There are two types of LCD monitors being sold by PACS vendors: monitors with internal photometers and monitors without internal photometers. In each case, a calibrated luminance meter or laptop computer with luminance pod and software should be used during the AT to validate the photometer measurements.
- Prior to beginning AT, basic information about each workstation should be recorded. The information should include
  - the workstation location
  - the display manufacturer and model
  - the pixel matrix
  - the graphics card manufacturer and model
  - the number of monitors on the workstation
  Note: if the workstation is constructed with an additional monitor for HIS/RIS or textual information and/or color display of images, then record the additional monitor information.
- Monitors with internal photometers are calibrated outside the PACS application. (The internal photometer application checks the monitor’s calibration when the workstation starts or boots up and does not use the PACS application.)
- The AT team will need to coordinate with the PACS vendor so the AAPM TG-18 image set can be loaded into the PACS.
The monitor calibration and quality control software do not use the PACS display software, and it is important to have a set of standard images available to test against. The AAPM TG-18 images are available on the AAPM website in DICOM format (.dcm), in either a 1 k or a 2 k pixel matrix (Table 23.1).

Our Experience 23.19: Monitor QC
During one of our first ATs, the PACS application reserved the top range of luminance for text, so the maximum luminance measured on a monitor in the PACS application was less than the maximum luminance measured outside the application.

### Step-by-Step 23.20: Testing Workstation Monitors

<table>
<thead>
<tr>
<th>Testing step</th>
<th>Variations and comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum luminance</td>
<td>Using the TG18-LN12-18 test image measure the maximum luminance in the center of the monitor.</td>
</tr>
<tr>
<td></td>
<td>(The ACR/AAPM suggest a maximum luminance of at least 170 cd/m² for diagnostic monitors and 100 cd/m² for clinical monitors.)</td>
</tr>
<tr>
<td>Minimum luminance</td>
<td>Using the TG18-LN12-01 test image measure the minimum luminance in the center of the monitor.</td>
</tr>
<tr>
<td>Contrast ratio</td>
<td>Max. luminance/min. luminance</td>
</tr>
<tr>
<td></td>
<td>(The contrast ratio should be &gt;250 for diagnostic monitors and &gt;100 for clinical monitors.)</td>
</tr>
<tr>
<td>Contrast balance</td>
<td>Display the TG-18QC (or a SMPTE) test pattern and look for 5% and 95%. The perceived contrast difference between 0% and 5%, should be the same as the perceived contrast difference between 100% and 95%.</td>
</tr>
<tr>
<td>Luminance uniformity</td>
<td>Obtain luminance measurements of the four corners and the center of the monitor. The measurements should not vary more than 30%. Record the five luminance (cd/m²) readings for each monitor.</td>
</tr>
<tr>
<td>(Done on each monitor)</td>
<td></td>
</tr>
<tr>
<td>Workstation monitor uniformity</td>
<td>The center measurement of each monitor on a workstation should not vary more than 10%. Record the luminance (cd/m²) of each monitor.</td>
</tr>
<tr>
<td>(Reported for each workstation.)</td>
<td></td>
</tr>
<tr>
<td>Pixel drop-out</td>
<td>Pixel drop-out is indicated by dark specks in white images that do not change location when a different white image is displayed. Visually inspect the monitor for pixel drop-out by displaying a white or light grey flat field. Refer to</td>
</tr>
<tr>
<td>(Large numbers of missing pixels could distract a radiologist during interpretation.)</td>
<td></td>
</tr>
</tbody>
</table>

(Continued)
<table>
<thead>
<tr>
<th>Testing step</th>
<th>Variations and comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual evaluation of display noise</td>
<td>- Display noise is evaluated using the TG18-AFC test pattern. The test image is divided into four quadrants. Each quadrant is divided into 48 squares, with each square having a low contrast dots in random positions within the squares. The contrast-size values for the target dots are a constant in each quadrant, but the values are different for each quadrant. The image is viewed at a distance of 30 cm, at the normal ambient lighting conditions in which the workstation will be used. On a calibrated monitor used for primary diagnosis, the evaluator should be able to determine the location of all of the dots in 3 out of the 4 quadrants. On other calibrated monitors, the viewer should be able to determine the location of the dots in 2 out of the 4 quadrants.</td>
</tr>
<tr>
<td>Visual evaluation of display chromaticity.</td>
<td>- In LCD monitors, the color tint of grayscale monitors can be affected by the spectrum of the backlight and by the viewing angle. Grayscale monitors used for primary diagnosis on multi-monitor workstations should be matched for tint at the factory, and sold and installed in matched sets in order to avoid perceivable differences in the tint of monitors on the same workstation. To perform this test, display the TG18-UN80 test pattern on the grayscale monitors. Note any perceivable differences in the relative color uniformity across the display area of each monitor, and between the monitors on the same workstation. The observer must be looking straight on at the monitor in order to reliably perform this test. Angled viewing will result in an invalid test.</td>
</tr>
</tbody>
</table>
Table 23.1

<table>
<thead>
<tr>
<th>MONITOR EVALUATION WORKSHEET</th>
</tr>
</thead>
<tbody>
<tr>
<td>WORKSTATION #/</td>
</tr>
<tr>
<td>Place an “X” over non-relevant monitors</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Workstation Type</td>
</tr>
<tr>
<td>B/W or Color</td>
</tr>
<tr>
<td>Maximum Luminance (cd/m²)</td>
</tr>
<tr>
<td>Minimum Luminance (cd/m²)</td>
</tr>
<tr>
<td>Contrast Ratio</td>
</tr>
<tr>
<td>Contrast Balance</td>
</tr>
<tr>
<td>Luminance Uniformity</td>
</tr>
<tr>
<td>Workstation Monitor Uniformity</td>
</tr>
<tr>
<td>Pixel Drop Out</td>
</tr>
</tbody>
</table>
23.4 Conclusion

The acceptance test of a PACS is an important evaluation of the performance and availability of the information systems, modalities, and PACS components connected across a network. In addition to a system inventory, certifying contract

### Pearls 23.21

- PACS acceptance testing validates that the system components are operational and communicating to the information systems and modalities.
- DICOM supports the information and image workflow between the PACS, information systems, and modalities.
- Thread testing allows the user to emulate each piece function of the real-world workflow from order, to acquisition, display, interpretation, and final report.
- Archive testing is done to ensure that images are retrievable in the same format or context they were originally acquired.
- The AAPM TG-18 image sets should be used to consistently test workstation monitors.

<table>
<thead>
<tr>
<th>Monitor Evaluation Worksheet (Continued)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Display Noise</strong></td>
</tr>
<tr>
<td>(Using the TG18-AFC test pattern visually inspect the monitor. The contrast-size values for the target dots are a constant in each quadrant, but the values are different for each quadrant. The image is viewed at a distance of 30 cm. On a calibrated monitor used for primary diagnosis, the location of all of the dots in 3 out of the 4 quadrants should be seen. On other calibrated monitors, the viewer should be able to determine the location of the dots in 2 out of the 4 quadrants.)</td>
</tr>
<tr>
<td><strong>Display Chromaticity.</strong></td>
</tr>
<tr>
<td>To perform this test, display the TG18-UK80 test pattern on the grayscale monitors. Note any perceivable differences in the relative color uniformity across the display area of each monitor, and between the monitors on the same workstation. The observer must be looking straight on at the monitor in order to reliably perform this test. Angled viewing will result in an invalid test.</td>
</tr>
<tr>
<td><strong>Comments:</strong></td>
</tr>
</tbody>
</table>
compliance, and identifying deficiencies, an AT is a technical evaluation of a system that demonstrates readiness for clinical use and a baseline for a facility’s quality control program that will monitor the PACS in the future.

Self-Assessment Questions

1. The best time to define the PACS acceptance test requirements is
   a. during user training
   b. after the PACS is installed.
   c. in the request for proposal that the vendor responds to
   d. All of the above
   e. None of the above

2. The HIS/RIS/PACS and other medical information systems connect with each other using
   a. a robust, secure network connection
   b. DICOM
   c. HL7
   d. All of the above
   e. None of the above

3. DICOM connections between the PACS and modalities include
   a. IP address
   b. System license
   c. AE title
   d. Port number
   e. A, C, & D

4. DICOM image sets used for evaluating workstation monitors are available from
   a. RSNA
   b. IHE
   c. SIIM
   d. JCAHO
   e. ACR/AAPM

5. Which of the following are used for PACS image storage?
   a. Short-term storage
   b. Long-term archive
   c. Redundant or disaster recovery archive
   d. All of the above
   e. None of the above
Part VI
Strategy and Vision: PACS Administration
Associate Editor: David L. Weiss
Chapter 24
Working with Vendors

David E. Wild

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24.1 Introduction

The purpose of this chapter is to provide insight on, and the perspective of, vendors to imaging informatics professionals. The areas covered will include vendor selection and an overview of the vendor selection process; management structure of organizations and factors that impact how a product/technology is developed.

As part of any vendor selection, customers evaluating technology should allow each vendor involved to present their technology under the best possible conditions in the most unbiased way possible. Preferences of vendors and relationships with people are very important to any sales process; however, the cultivation of “competition” among vendors generally will always yield the best understanding of the technology acquired. Limiting the ability of vendors (both large and small) to compete and present information will inherently limit the understanding of the technology acquired.
24.2 Vendor Selection

Choosing a vendor for a project involves several considerations: product offering, service offering, company history, financial feasibility, evaluation of technology, and clinical impact to a department or enterprise. This section will describe the process of a vendor through the technology acquisition process. Customers should have insight into the sales process from a “vendor” perspective to assist customers to identify the best technology for their institution.

24.2.1 Overview of the Vendor Selection Process

24.2.2 Sales Strategy and Relationships

To be successful at winning business, customers should understand key areas that allow vendors to compete and win business. The attributes that allow vendors to be successful are mutually beneficial for the customer; they help to build clarity regarding both the technology acquired and the company that will support their needs.

When vendors begin the sales process, a sales strategy is formulated. The purpose of this strategy is to evaluate the opportunity, understand the best solution to offer, and determine those people that will influence the decision to acquire technology.

Vendors’ ability to be successful in selling frequently is the result of building personal relationships with the customer.

These relationships can be cultivated with those people in the department who understand the department along with key decision makers. Vendors are very thoughtful about “product positioning” to highlight how technology can help to overcome pain points in the department.

Checklist 24.2: Key Information for Vendors

- **Understand the department**: Vendors visit your department to cultivate and try and build relationships.
- **Key decision makers**: Vendors always look for those who make key purchase decision, which *may* or *may not* exist in the department.
- **Product positioning**: A demonstration of a product is scripted production; defined to display product with best possible approach.
- **Pain points**: Vendors try to understand current difficulties to show how their product overcomes them.
• **Understand the department:** When purchasing technology, members of a department or institution provide significant insight into the purchase decision; even though they may not actually make the final purchase decision.
  – Provide insight into the key areas that will impact the decision to purchase the technology.
  – Explain existing vendor preferences and perceptions of vendors or vendor technology.
  – Define current and desired workflow supported by technology acquisition.

• **Key decision makers:** Provide the most influence when acquiring technology.
  – Direct influence over the decision to purchase technology.
  – Needs and concerns in the department are closely examined based on impact of technology acquisition.
  – Those who influence the decision and control the purchase of technology may not be within the department.

• **Product positioning:** Vendors success depends on how a product is positioned to meet the requirements and goals of a department.
  – Vendor will demonstrate “what is possible” with their technology.
  – Vendor success depends on the vendor gaining enough access to the department to help define how technology will emerge once in clinical use.

• **Pain points:** Those hurdles and challenges that cause a department to function sub-optimally. The results can influence lost revenue, create inefficient workflow, or limit the best possible patient care.
  – To be successful in sales vendors must understand the difficulties that exist in the department. Understanding these pain points is what allows vendors to position technology to improve a department or facility.

If a vendor can be successful at building a relationship with a customer and learning about their problems, understand the department, and position a product to influence key decision maker, that vendor will have a greater likelihood at winning business.

### 24.2.3 Request for Information (RFI)

The request for information process is typically used to determine which vendors will complete in an opportunity (i.e., “who will receive the RFP”); it is used as an evaluation of a vendor’s product portfolio to determine if a product matches the needs of a customer. Vendors view a request for information as a means to an end to examine the opportunity and determine if the product will be viable for inclusion in the opportunity. **The goal of an RFI: to receive the RFP.**
24.2.4 Request for Proposal (RFP)

RFPs are a required part of the sales process, and consequently, companies (large and small) have defined tools and methods to respond to them. The RFP response is beyond completing a document and allowing customers to assess product functionality, pricing, architecture, etc. The RFP is a tool vendors use to highlight and market their technology and company to the customer evaluation team. It is often said, “You never win a deal from an RFP, you can only lose a deal from an RFP.”

Definition 24.3: Request for Information (RFI)

A document delivered to vendors as part of a product selection process. The document describes attributes necessary to be included in a request for proposal. These attributes can vary but typically include information about the company, product portfolio, and experience in the relevant field. Based on the results of an RFP, a customer will decide whether to include the vendor in the product selection process.

Definition 24.4: Request for Proposal (RFP)

Document distributed to vendors to solicit information related to the acquisition of a product or service. The RFP may request information related to the company, product, service offering, and pricing for a product of interest. The document will also provide specific information about the organization evaluating the technology, including facilities, volume, technology infrastructure, and workflow. An RFP will also provide logistics related to the timing and format of responses.

Things to know about RFPs:

- **Who responds to an RFP:** When vendors receive an RFP, depending on the size of a company, it is typically completed by
  - Sales staff
  - Marketing staff
  - Dedicated staff to complete RFPs
  - A combination of these groups
- **Responses to questions:** Vendors have cataloged responses for RFPs; in almost all cases, RFP responses are cataloged into a collection/pool for reference.
- **RFP Questions:** The number of RFP questions recycled is very high; as a result, vendors become familiar with the responses that customers or third parties are looking for.
- **Strategy to answer questions:** Answers to questions may be subjective based on a vendor’s technology offering. Vendors all have different methods to overcome department and users’ needs; however, that solution may not be
“optimal” for a customer’s needs. As a result, the response solicited in an RFP such as “comply,” or “Yes, fully meets expectations” are accurate but different from a site’s expectations. Vendors’ responses are designed to highlight the strengths of companies.

- **Pricing quotes for RFPs:** Software quotes based on “volume” of studies or “seat licenses” are typically easier to quote in an RFP than “hardware configurations/architecture.” This is because “volume” and “# of users” are easy information to provide. Most sites know their current volume and growth and the number of users they have.

Vendors vary in technology and required hardware platforms. This variance, without significant discussion, can cause discrepancy in pricing when comparing vendor costs in an RFP. The RFP process may not provide the necessary dialog needed to develop the most accurate quotes possible. For example, will a customer include details related to disaster recovery and business continuity architecture (what are plans for backup or recover), or storage requirements for how long data will be required to be available. This type of information is very valuable when building an accurate quote.

In addition, RFPs typically include minimal information related to workflow, which may also impact a vendor quote. So to request a quote as part of an RFP, there should always include some detailed discussion with a vendor if you expect to compare product pricing accurately (within the RFP). Having vendors include quotes without significant discussion regarding the exact system will rarely produce accurate price quotes with “apples-to-apples” comparisons. Rarely will the RFP quote be the final quote for the vendor of choice; there is always additional negotiation or clarification that changes the price of a product reflected in the RFP before technology is acquired.

### 24.2.5 Onsite Product Demonstrations

Onsite product demonstrations are given by professionals trained to highlight the strengths of the product and company. To achieve the most out of a product demonstration, the site should work closely with the vendor to make sure current department and workflow limitation are known before the demonstration. This allows vendors to customize the demonstration for the specific site. When product demonstrations occur with little warning, the

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**Definition 24.5:**

**Vendor of Choice (VOC)**

When conducting an evaluation of technology, the VOC is preferred vendor of an institution based on initial information. “Due diligence” is the process of confirming that the VOC is the best choice for the institution.
result is typically a generic demonstration of technology with limited customization.

Those customers who request “test systems” left onsite should request a trainer to be available to educate users regarding the optimal workflow for the system. In addition, when systems are onsite, it should be incumbent upon an imaging informatics professional to ensure that someone from the institution is trained on the system. If users are not well trained on a system it becomes difficult to evaluate it, as they typically do not use it with proper efficiency.

24.2.6 Site Visits

To achieve a successful site visit, the first question to ask is “what is the purpose of a site visit”? Site visits require significant consumption of resources for everyone involved (customer, vendor, visit location). They use valuable time; away from the office, produce the headaches of travel, cause disruption of workflow for those hosting along with many other issues. However, with all of those issues they do serve a valuable purpose for both the vendor and customer.

24.2.7 Vendors and Site Visits

As a vendor, a site visit is designed to provide a positive reflection of both the vendor and overall experience with the product.

In addition to a great team, a site’s willingness to host visits and showcase their institution produces a strong site visit location.
24.2.8 Why Host Site Visits?

A show site’s time is valuable, and the effort to devote time to a visit typically results in some type of quid pro quo, or formal arrangement between the site and the vendor. These benefits may manifest as price concessions, additional professional services, and other institutional support.

Checklist 24.9: Show Sites

What makes for an excellent show site? Typically, the same attribute that makes for successful patient care...a great team! Those who host site visits characteristically all have three things in common

1. Strong leadership
2. Well-trained employees
3. Commitment to user satisfaction

Those who host site visits can receive benefit for their effort. That benefit occurs in a variety of forms:

- Monetary
  - Product pricing via discounts for purchases
  - Institutional support for philanthropic activities
- Service and support
  - Enhanced support and maintenance
  - Greater escalation of site related issues
- Product enhancements
  - Increased visibility into the product roadmap and direction
  - Increased influence over product enhancement process (request for features)

24.2.9 Visiting and Evaluating Show Sites

The primary purpose of a site visit is providing “an experience” not just with a product but also with a company.

To achieve the greatest success on a site visit, a potential customer should assess beyond the specific technology that is used; but how it is used; within a department workflow and across an institution. In addition, imaging informatics is a small industry and introductions during site visits to cultivate professional relationships for continued follow-up and knowledge sharing is a valuable tool for the vendor and the customer.
24.3 Organization and Technology Evaluation

When purchasing technology, investigation should occur about the company selling the product, and how the product is developed and evolves. This information allows a customer to evaluate the long-term viability of an investment; and they can expect it to evolve.

Checklist 24.11: Things to Learn About a Vendor

To evaluate an organization, customers should strive to gain the most information possible about a vendor. Areas to understand include

- **Management team** – overall responsibility for the product and those who support the organization. Has knowledge over the strategic direction and growth of the organization.
- **Marketing** – influence over product direction, assess market needs, assist with prioritizing client requests. Typically has most knowledge of product direction (along with engineers designing the product).
- **Sales/account management** – responsible for product sales and is the primary contact for an account. Has access to other clients who use same technology.
- **Service/support** – responsible for responding and resolving product issues; provide information related to the success of upgrades and continuous product monitoring.
- **Research and development** – responsible for the development of the product; oversees engineering group dedicated to development.
- **Commercial/billing** – responsible for order processing, billing, and terms and conditions related to the acquisition of technology.
24.3.1 Product Development

Products evolve in many different ways and there are several influences over what is developed, and when products are developed. When considering a purchase, investigating why products’ features are developed and how they evolve provides valuable insight into what a product will evolve into after acquisition.

Depending on the vendor and product, development is influenced in a variety of ways. Market direction and client request play a significant role. In addition, the product-release cycle can also affect product development.

- **Market direction**: Outside factors that influence the development or enhancements of technology. Market direction is always evolving and by understanding those forces that influence the market direction, they give consumers an insight into product development process.

- **Client request**: Clients evaluating vendors should understand how vendor enhancement request is cataloged, evaluated, and developed. Vendors receive several requests for product enhancements and evaluate the request related to existing product functionality, scope of change, and impact of changes to other users of the product.

- **Product release cycle**: The process and duration to update and publish releases to a product. Product release cycles vary by type product and vendor. Factors that can influence the product release cycle include the size of a company, development platform (recent or legacy), number of engineers, and requirements by regulatory agencies. When assessing technology, investigate how frequently product enhancements occur and what the upgrade path is.

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**Our Experience 24.12: Market Direction**

As Internet bandwidth exploded, more “teleradiology practices” formed. The PACS market needed to include tools and features to meet those needs of “teleradiology.” This is in contrast to when the PACS market began, and images were almost exclusively interpreted onsite within a facility.

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**Key Concept 24.13: Product Vetting**

All vendors have a process for vetting product enhancements. As part of a technology evaluation, the customer should have knowledge of the process from request through software release. In addition, the customer should understand what charges or fees are associated with software enhancement requests.
**Pearls 24.14**

- A request for information is sent to many vendors and contains general information about the technology requirements.
- A request for proposal is sent to a limited number of vendors and contains extensive specific information about the institution.
- Vendors want to evaluate the opportunity, understand the optimal solution, and contact the correct people to facilitate the vendor–customer interaction.
- Onsite product demonstrations are used to demonstrate how the system works under idealized conditions.
- Site visits are used to demonstrate how the system works in real-life conditions.
- Customers should become extensively familiar with the business practices of their vendor of choice before committing to a purchase.

**Self-Assessment Questions**

1. Which of these best describes a request for information?
   a. Contains detailed information about the customer’s institution
   b. Sent to a large number of potential vendors
   c. Follows the request for proposal
   d. Determines the vendor of choice

2. Which of these best describes a request for proposal?
   a. Contains detailed information about the customer’s institution
   b. Sent to a large number of potential vendors
   c. Determines which vendors receive a request for information
   d. Determines the vendor of choice

3. Which of the following is LEAST influential in product development?
   a. Customer requests
   b. Market direction
   c. Site visits
   d. Product release cycle

4. Which of the following is LEAST important to assess on a site visit?
   a. Compare clinical workflow between institutions
   b. Discuss installation issues
   c. Show interaction with other information systems
   d. Compare pricing between institutions
5. Imagine that your institution is a host site for a site visit. What issues would you discuss with the visitors? What software would you show them that is unique or unusual in your environment?

6. When you are deciding upon a vendor of choice, what aspects of the vendor’s business factor into that decision.
Chapter 25
Team Building and Project Management

Kevin W. McEnery

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25.1 Introduction

The successful implementations of PACS have revolutionized the healthcare delivery in those institutions with successful deployments. Numerous vendors have available systems that deliver on the promise of PACS to provide imaging delivery without the need to be tethered to the physical transportation and delivery of film-based images. As PACS has entered the “Late Majority” phase of innovation implementation, there is no need for new entrants to worry about a successful final outcome if they follow the best practices of project and change management. The cultural barriers to PACS adoption should be minimal. The purpose of this chapter is to provide guidance from the “lessons learned” from numerous successful implementations.
25.2 Members of the Project Team – Team Building

The implementation of a PACS is a complex process that involves both the imaging department and its effects on the large enterprise. Once an institution makes a decision to investigate implementation, a “PACS committee” must be formed to guide the project and serve as a conduit for PACS project coordination activities. The size and constituency for this committee will vary based on the implementation components. A freestanding imaging center will require a smaller committee than a multi-hospital integrated healthcare delivery system. Regardless of the anticipated size of the implementation, membership should be representative from groups directly affected by the PACS system. Furthermore, from the outset, there must be executive leadership and buy-in that the project is essential to future financial performance and clinical outcomes. Given the number of constituencies served by the PACS system, the PACS committee serves to represent all parties in the buying and implementation decisions.

25.2.1 PACS Operations Workgroup

While the PACS committee can establish the “big picture,” most PACS administrators find it useful to form a second group of individuals who are involved in the operational aspects of the PACS deployment. The purpose of this workgroup is to discuss and collaborate on the resolution of issues which the project plan requires completion or to hopefully efficiently resolve unexpected issues.

- The workgroup membership should include membership from those groups who are actively participating in the PACS implementation. This should include but not be limited to the PACS administrator, PACS support personnel, project manager, RIS manager, imaging physics representatives, vendor representative, desktop IT support, and network administrator.
- A meeting agenda should be followed which continually tracks open issues and their resolution.
- The meeting document can be saved on a shared hard drive for reference during the week by team members.
- Over time, this operations workgroup should function at a high level of efficiency continually resolving problems and updating open issues.

25.3 Identify Goal, Scope, and Risks

Implementation of PACS is a complex process with many successful projects to guide implementation. At its core, a PACS project is an IT project implementation with numerous co-dependencies on other systems within the institution. The cultural changes required during a PACS implementation have been
Checklist 25.1: Members of the PACS Committee

Radiology Representation
- Chief radiologist – Department Chair. This person presumably has the authority oversight for many aspects of the clinical practice.
- Radiology department manager/administrator.
- Radiology operations manager.
- Radiology information system manager.
- Chief technologist(s) – the number of technologists necessary on the committee will vary for the sign of the practice and the organization structure.
- Chief of service for group responsible for imaging equipment – in some practices, this will be imaging physics or biomedical systems.
- Radiologists – modality section leaders.
- Radiologist champion – this person will be expected to assist the project in encouraging and coordinating radiologist participation – may be one of the above radiologists.
- Radiology nursing representative (or institutional nursing).
- PACS administrator – when organization already has PACS installed and project is upgraded from existing system.
- Contracts and purchasing officer (local or from institution).
- Project manager.

Institutional Representation
- Referring physicians – include imaging intense specialties such as emergency and ICU medicine, cardiology, orthopedics surgery, and neurosurgery.
- Chief medical information officer.
- Information system representative (CIO or a direct report).
- IT infrastructure representation – coordinate network and physical plant infrastructure (HVAC, space, power).
- Electronic medical record and/or medical records department representative.

CHECKLIST 25.2: PACS Committee Responsibilities

- Set clinical and operational goals for PACS project.
- Establish PACS project scope and ensure project remains within the scope.
- Allocate necessary resources to implement project plan.
- Ensure that all roles and responsibilities are defined in the project plan.
- Develop and approve detailed PACS project plan.
- Provide project oversight.
- Serve as a communication resource for all the constituent groups represented on the committee.
- Schedule regular meetings to review PACS project milestones. At a minimum, monthly during project implementation – consider biweekly during initiation and vendor selection phases.
well described and can be anticipated. For sites embarking on PACS implement-
ation for the first time, there will likely be interactions with members of the
hospital’s technical and physician staff that have not previously occurred but
are crucial for the overall success of the project. For those sites planning on
upgrading their existing PACS system to a new version or even a new vendor,
the PACS upgrade provides the opportunity to re-establish project teams and
committees largely responsible for the success of the initial implementation.
Whether implementing PACS for the first time or upgrading, the project
provides an imaging department and the institution the opportunity to decide
the specific goals of the system and the measures for clinical and financial
success.

25.3.1 PACS Project Goals

- An initial focus of the PACS committee must be to create a project charter
  that defines an overriding goal for the entire project. Although each consti-
tuent group will bring to this group their own perspective on how the project
will affect their area, the success of the project depends on the alignment
of individual goal.
- A good place to start to initiate alignment is in the context the institution’s
  mission statement and then poll individual stakeholders to obtain perspective of
  how the PACS system would allow them to achieve their mission specific goals.
- A common goal of many initial PACS installations was to “eliminate film.”
- With the expansion of PACS outside of the imaging department and increas-
ing integration of imaging into the electronic medical record (or future
electronic medical record) the implementation of a PACS can provide clin-
ical and efficiency benefits across the healthcare enterprise.
- Alignment of PACS project with the institutional mission and goals provides a
  higher level of visibility for the project as it competes for institutional resources.
- This is also an important team-building activity as it provides all stake-
holders an opportunity to understand and appreciate the variety of different
needs and expectations of the PACS project on various committee
constituencies.
25.3.2 PACS Project Scope

- Once the project goals are established, **specific project deliverables** must be defined which achieve the project goals. Specific project deliverables directly affect the project plan and resource allocation.
- The project “**Statement of Work**” should explicitly define which areas of diagnostic imaging operations are included in the project and which areas are excluded from the project.
- A **change management process** should be agreed upon by the committee in advance to deal with those instances where the PACS project chose not to address a specific area or a new area of work presents itself. A formal change management process allows the appropriate allocation of existing resources or the request for additional resources.

25.3.3 Common Risks for PACS Projects

As an information technology project, PACS is subject to failure for the same reasons that other IT projects fail. While the risk is high because of the diversity of stakeholders involved by the process, it is mitigated to a degree by the fact that PACS are no longer novel and there are many instances of proven successful implementations in a variety of practice settings.

Reasons why a PACS project could fail include

- PACS committee member representing their own personal interests and opinion and not those of the group they were selected to represent.
  - **End-user surveys** can prove a valuable tool to validate or guide the PACS committee assumptions and priorities.
- Inadequate **communication** from PACS project to end users with users not actively participating in project success.
- Lack of training opportunities or training in a test system that did not simulate **local work environment**.
  - Generic system workflow employed in test environment differs from existing workflow with no user expectation or plan to change site’s workflow.
- Failure to understand the **culture of the institution** with regards to **IT-enabled change**. Generally, there will be resistance to change, especially in those organizations that have not adopted other electronic clinical systems (EMR, order entry, electronic results review, etc.).
• Aggressive deployment schedule with no accommodation for unexpected events.
• Failure to provide a small-scale pilot project to validate project assumptions.
• Lack of a back-out plan in the event that system “go-live” demonstrated unexpected critical project defects.
• Implementing two unproven IT systems on the same “go-live” event – for example, implementing voice-recognition software along with PACS.
• Lack of detail in project plan with minimal detail in contract Statement of Work.
• Unrealistic deadlines results in project delays and cost overruns for non-budgeted system change requests.
• Failure to provide necessary network infrastructure or anticipate systems interface requirements to the hospital information system (HIS) or radiology information system (RIS).

25.3.4 Risk Mitigation Strategies

• Communication and training strategy should be defined in project plan.
• Potential vendors should provide examples of successful project implementation plans in similar size institutions.
• Limited deployment of system with parallel workflows.
  – In transition from film to PACS continue to print film during pilot and initial deployment.
  – In transition to new PACS vendor – continue to utilize existing PACS system during pilot in parallel to new system.
• Vendor should submit a detailed environmental survey as part of signed contract that outlines all anticipated integration interfaces and integration responsibilities.
• Acceptance of detailed project plan should be part of the contract negotiation with selected vendor including specific remediation steps agreed upon prior to implementation.

25.4 Evaluate the Feasibility of a Project

In the early days of PACS, whether images could be efficiently and effectively digitally captured, interpreted, and distributed was often open to debate. The perseverance of early adopters has matured into readily available vendor systems fully capable of meeting the promise of fully digital medical imaging. The feasibility focus is now more concerned with the infrastructure and needs requirements of a commercial PACS system in a given clinical environment, including integration with other hospital data systems.
25.4.1 Local Environment Assessment

- Available resources for project management should be identified.
- Existing infrastructure needs to be fully assessed. PACS functions optimally with high-availability network infrastructure.
- Existing reading areas need to be converted into digital workspaces or other spaces identified.
- PACS is most easily deployed in an environment of completely digital image acquisition. Most existing devices should be DICOM compliant.
- Advanced workflow features of PACS such as modality worklist management can be implemented prior to PACS implementation.
- Offsite clinician and radiologist image access in facilitates with available virtual private network (VPN). If offsite image access is desired, then VPN access infrastructure is required.
- Does local imaging physics expertise exist to assist with PACS monitor calibration and maintenance? This expertise will need to be established in-house or contracted with a third-party. Experience has demonstrated that gray-scale digital amorphous silicon monitors are much more reliable than initial analog monitors.
- Do the radiologists expect to have access to the Internet while they are interpreting images?
- Does the institution have an existing EMR or other ancillary system and which of these are necessary for technologists, nurses, and radiologists to perform their job function? How does the PACS integrate with this system?

25.4.2 Financial Feasibility

- Most institutions have a defined project approval process for large IT and hospital projects. The PACS committee must understand this approval process and determine the likelihood of successful funding. PACS project plans and funding requests must be submitted into the applicable approval framework to enable the highest likelihood of project approval.
- Recommendation at the outset of considering a PACS project: the imaging department approach hospital administration or applicable funding source as to the possibility of implementing a PACS project. From the outset, involvement of appropriate stakeholders from outside of diagnostic imaging
will provide the appropriate context that a PACS project benefits not only diagnostic imaging but also the efficiency and effectiveness of the entire institution.

- Implementation of traditional PACS typically entailed a large capital investment to purchase necessary workstations and storage modalities.
- There are a large variety of alternative PACS funding models available today including both traditional capital purchase systems as well as operational cost models where a fee is paid for the storage of individual examinations. It is also possible to purchase PACS software from one vendor and the storage archive from another vendor.
- The PACS committee must fully understand the procedure volume, average study size, and anticipated procedure volume growth to provide an accurate model of overall system cost.
- Factors impacting on the overall cost of PACS implementations include the number of anticipated workstations, concurrent users both within radiology and the enterprise.
- Advanced visualization workstations are typically an additional project cost. A determination needs to be made as to whether the radiologists and clinicians expect this functionality.

### 25.5 Common Project Management Tools

The principles of project management can be applied to any project requiring the coordination of numerous resources over an extended period of time. PACS implementations are well suited for a project management framework. A project management framework also allows all those involved in project execution to make specific decisions regarding the project scope, quality, time, and budget. These project constraints provide the context for which the PACS project will be judged as well as allow rational decisions regarding project timelines and budget. For example, reducing the scope of a project will usually shorten timelines and decrease budget. Conversely, allowing the scope of a project to widen without appropriate oversight during its execution will invariably lead to missed project deadlines and budget overruns.

In most institutions, the project management framework is well established and one needs to be aware of the project management framework utilized in a given institution. The framework usually follows a traditional project management process designed to provide a consistent process for all project management within an institution.

**Definition 25.6: Project Management**

The discipline to plan, organize, and manage resources to provide optimal project outcome.
25.5.1 Project Development Stages

Regardless of the methodology used, the project development process will have the similar major stages. At some institutions, these phases are combined and at other institutions the phases are divided into sub-phases.

Step-by-Step 25.7: Traditional Project Management Process

1. **Initiation**: Identification of the business need.
2. **Assessment**: Involvement of stakeholders to define project charter and scope as well as risks.
3. **Planning**: Create detailed project plan including communication and training strategy. Vendor selection occurs during this phase.
4. **Execution**: Project implementation as well as change management process.
5. **Monitoring**: Observation and verification of project deliverables to ensure project completed on time, within scope and on budget.
6. **Completion**: Performance reports, benefits analysis, lessons learned.

Checklist 25.8: Project Development Stages

- Initiation
- Planning/development
- Production/execution
- Maintenance/control
- Closure

Definition 25.9: Project Sponsor

The fiscal or administrative entity that has overarching responsibility for the project.

Our Experience 25.10: Project Stages

At M.D. Anderson Cancer Center, project execution and initial analysis of project completion are combined into a single step appropriately entitled “Execution and Control.”

1. **Initiation Phase**
   - **Project charter** is developed and initial approval for project planning is received.
   - **Project sponsor** is identified as well as stakeholders who will participate in oversight group.

2. **Assessment**
   - Determine **business needs** that project is targeting.
   - Review existing **workflow operations**.
• Determine existing IT environment including necessary IT system and imaging modality interfaces.
• Determine end-user requirements:
  – Radiologists
  – Technologists
  – Nurses
  – Management
  – Customers (i.e., referring clinicians)
• Develop project specification documentation.
• In this phase, it is very important for the committee to understand those requirements that are unique to their institution and to establish these as internal “discriminator criteria.” These criteria should also have higher weight in vendor selection scoring.
• Final project documentation, including budget, tasks, deliverables, and anticipated project schedule.
• Expected financial return on investment.

3. Planning
• Request for proposal review
• Vendor selection process
• Vendor site visits
• Vendor selection
• Contract negotiations
  – Must include development and approval of a project plan.
  – Change management process specification.
• Project milestones prior to PACS go-live.
• Acceptance criteria.
• System performance criteria as well as agreed upon definitions for system downtime and remedies.

4. Execution and Monitoring
• Implementation of system based upon project plan.
• Coordination of vendor and customer resources.
• PACS committee oversight of implementation.
• Observation of project milestones.
• Decision to have system activated.

5. Project Close
• Report on project completion of milestones.
• Budget reports and initial return on investment estimates.
• Compilation of lessons learned from the project.

25.5.2 Project Management Forms and Tools

In most formal project methodologies, formal project templates and spreadsheets are usually required by the institution or oversight group. In most
institutions, PACS project will likely be completing against other projects for limited resources and the PACS administrator and project manager must determine the appropriate formatting.

1. **Common Project Forms and Templates**
   - **Project charter** – contains project justification and expected outcomes including anticipated **return on investment**. Explicitly defines the **project scope** and serves as a reference to evaluate project change request. As a summary document, provides summary information to assist upper management in project approval and prioritization.
   - **Stakeholder involvement** – identifies key personnel to participate in the project and who have agreed to participate in project.
   - **Risk Identification and mitigation plan**.
   - **Initiation, planning, execution, monitoring, closing**.
   - **Budget and project reports (monthly)** – provides ongoing summary of project progress. This document shared with PACS committee documentation of primary project oversight. Usually this document also forwarded to institutional IT oversight committee.
   - **Personnel resource allocation** – provides listing of personnel currently assigned to project and their level/percentage of participation.

2. **Common Project Management Tools**
   - **Gantt Charts**
     - Invented by Henry Gantt (1861–1919).
     - Provide a sequenced view to project tasks and timelines.
     - Provide overview of tasks with expected initiation and completion usually represented in terms of weeks.
     - Can define who is responsible for specific task completion.
     - Gantt charts extensively utilized by most PACS vendors using Microsoft(MS) Project and available MS Excel Spreadsheets; numerous other software vendor products available that support chart creation.
     - Well-suited method where project tasks and resources are well established from prior implementations (Fig. 25.1).
   - **Project Evaluation and Review Technique (PERT)**
     - Developed by Booz Allen Hamilton to support development and building of Polaris submarines.
     - Designed for complex projects, especially those in research and design where time to complete specific tasks are not well established.
– PERT is intended for very large-scale, one-time, complex, non-routine projects.

- **RACI diagram** (responsible, accountable, consulted, informed)
  – Also referred to as the “responsibility matrix” diagram.
  – Defines the reporting relationships for primary stakeholders and project managers or participants.
  – In a spreadsheet matrix, task descriptions are defined on rows and involved roles in columns.
  – For each task, a designation of “R,” “A,” “C,” or “I” is entered that explicitly defines person’s role with regards to specific tasks.
  – Designed to mitigate ambiguous task assignments between project participants (Fig. 25.2).

- **Run Charts**
  – Typically measures a project outcome variable before and after system or process change.
  – Pertinent example – time to report imaging studies pre- vs. post-PACS.

**Definition 25.12: Run Chart**
A graphing model that plots a known variable over time.

- **Project web site**
  – Document sharing and ad hoc communication.
  – Contains links to all project documentation including meeting minutes and presentations.
  – Daily blog could be utilized by project manager to facilitate project coordination between scheduled meetings.
  – Access to training documentation for end users.
  – Should include Frequently Asked Questions as well as options for submitting questions.

![Fig. 25.1 Sample Gantt chart.](image-url)
25.5.3 PACS Administrator as Project Manager

One of the roles played by the PACS administrator is that of project manager. Traditionally, a professional project manager is involved in the implementation of a project and then steps aside when the project is placed into production status. Clearly, it is not the intention of a PACS administrator to step aside once the PACS project is completely implemented. During the implementation of a PACS project the PACS administrator may be fully engaged simply implementing tasks required by the project plan of the institution. The dual role of project manager and PACS administrator may become overwhelming.

- PACS vendors, as part of their contractual obligation should be required to provide a project manager to coordinate all the activities of the vendor in the implementation of the project plan.
- The PACS customer should also have their own project manager who oversees the resources of the available from the institution. The PACS Manager can assist in all aspects of implementation including acceptance testing, system configuration, workflow re-engineering, and user training.
- In the initial PACS implementation the site should strongly consider hiring a project manager with previous PACS implementation experience. Ideally,
this person, usually a PACS consultant, should be hired at the initiation of the PACS project to contribute to the development of the specific requirements for the PACS implementation and the development of the project plan.

- Project manager should collaborate with the PACS manager in the coordination of specific administrative and implementation activities specified in the implementation contract as the responsibility of the site.
- Upon completion of the PACS project implementation, the PACS manager should assume responsibility for daily system maintenance and local oversight.
- The PACS Manager should continue to employ aspects of project management in the ongoing system maintenance including formal change management process.
- With this increasing experience, at the time of either vendor upgrade or decision to change PACS vendors the PACS administrator could consider assuming the role of project manager.

**Pearls 25.14**

- PACS committee representation should include key stakeholders both within diagnostic imaging and within the supported enterprise.
- End user surveys should be completed both to ensure alignment of PACS committee assumptions as well as provide higher level of end-user alignment.
- The project plan serves to maintain the scope of the project as well as to focus the project on specific milestones and deliverables.
- PACS should be initiated in a small pilot area with the capability to “back-out” of the project.
- The traditional project management process can be applied to PACS both for the deployment of the major PACS project as well as the inevitable follow-up projects.

**Suggested Reading**


Self-Assessment Questions

1. In the project management process, selection of the stakeholders who will participate in the oversight group occurs in phase
   a. Initiation
   b. Assessment
   c. Planning
   d. Execution
   e. Monitoring

2. In the project management process, vendor selection occurs in which phase
   a. Initiation
   b. Assessment
   c. Planning
   d. Execution
   e. Monitoring

3. Roles of the PACS committee include all except
   a. Ensure that any request for changes in the PACS plan align with initial project scope
   b. Review project plan to ensure it represents the clinical and technical requirements
   c. Serve as a project advocacy group in requesting of institutional funding
   d. Serve as an oversight group for project milestones and proper budget spending
   e. Ensure the current dominant modality vendor receives the PACS project contract

4. PACS committee membership should include in the stakeholder group
   a. Hospital IT representative
   b. Cardiologists
   c. Imaging physicist
   d. Medical records representative
   e. All of the above

5. The RACI matrix in project management is an acronym for
   a. Responsible, accountable, consulted, informed
   b. Representative and actionable contact information
c. Reasonable action for consultant information
d. Responsible activity for continual integrity
e. None of the above

6. This project management coordination tool presents a graphical display of key project milestones tracked over time

a. Run chart
b. RACI matrix chart
c. Gantt chart
d. Cause and effect chart
e. PERT matrix chart
Chapter 26
Long-Range Planning

Bradley J. Erickson

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26.1 Introduction

IT planning is a topic that gets both too much and too little attention. Frequent, there is much attention to plans at very high levels and at very low levels. The challenge is bridging that gap. In addition, high-level plans are not necessarily long-range plans, and it is important to have management strategies to assure that low-level planning continues and that there is a high level of consistency.

Most of what is included here is common sense. The value here is to help serve as a checklist to make sure that you do not forget something as you proceed.
26.2 Before the First Meeting

26.2.1 Strategy vs. Tactics

During goal and plan creation, the term “strategic” is often overused and erroneously substituted for the word “important.” Many plans are important but not strategic. However, describing a plan as “tactical” may imply that it is less important than a strategic plan. Both strategic and tactical plans are essential for successful projects.

Therefore, strategy and tactics should be in harmony and complement each other and are often sequential. From this perspective, it may also be that tactics are more important than strategy!

26.2.2 Define Goals Before the First Meeting

Altruism is not good enough – understand why you are doing this, as well as those around you.

- **Personal**: If this proceeds as you hope, will you be happy and satisfied?
- **Business**: How will this benefit the business/hospital? Do all see it that way?
- **Scope**: Where does the plan start and end? You should have a concept of this so that when the group gets excited and wants to “boil the ocean” you will have a cogent guideline about what you think is “in.”
- **Buy-in**: Who are the people critical to the success of the project?

Once you have defined your goals, make sure you write them down, and then set them aside for a week. Come back to them and review them. Do they still make sense?

In setting your goals, you set an anchor that can steady you. In setting these, you should not feel that they are immutable. The purpose is to keep the planning manageable, not to stake a claim on the project as forever only your vision. Indeed, most teams have individuals who will have invaluable contributions to make, and as a leader of the planning team, your job is to find and incorporate those gems.

26.2.3 Picking the Team

- All major stakeholders.
- Variety of skill sets and perspectives.
Find people who will stay involved, not “disruptors” or “bumblebees.”

26.3 The Actual Planning

26.3.1 Architecture

One of the first steps in developing a long-range plan is to consider architecture. Architecture used in this sense is much broader than any single plan. In fact, the architecture should be an essential element of all long-range plans being considered by your business. Planning a building means considering all its elements – the physical structure, the electrical, plumbing, HVAC systems, the aesthetics, and landscaping. In the same way, architecting your hospital’s IT environment involves multiple elements.

The components of your architecture should consider:

- Physical implementation – wireless and wired networking, storage, computing.
- Technologies (e.g., Microsoft.NET, Web services, etc.).
- Systems (e.g., HIS, RIS, PACS, 3D).
- Information (how you represent the actual content beyond simple ASCII text).

Each of these depends on the lower layer (Fig. 26.1), and the simpler the layer beneath is, the easier implementing and maintaining the higher layers will be.

Our Experience 26.3: Bumblebees

We sometimes the term “bumblebee” to refer to people with good ideas but little interest in implementation, who will want to move on after they develop an interest in something else or get frustrated because their ideas are not immediately adopted without hesitation. They can be useful, but should not be made essential to the project.
26.3.2 Identify Relevant Standards

An important part of developing your architecture is identifying relevant standards and selecting those best suited to your business needs. Then expect they are used.

- **DICOM** is a no-brainer since it enjoys near-universal support. Adopting IHE profiles is more challenging.
- **IHE** (not truly a standard, but has defined frameworks for existing standards like DICOM and HL7) should be a target – the availability of IHE products is less pervasive.
- In addition, IHE does not yet cover all aspects of enterprise workflow.
- **Adopting standards where possible** is critical to a long-term architecture because you will be able to select a greater range of vendors and products to fit within your architecture.

When do you break with standards?

- When functionality essential to your department can be delivered in no other way. This is rare – you just need to scratch your head more.
- When the cost of using “standards” is 20% greater for capital equipment, or 40% greater for process changes. (Rough heuristics – the point is it is easy to change out equipment, so the cost to use non-standard equipment for a while is easier than the cost of changing a key business process.)

26.3.3 Plan to Share

- Increasing economic pressures to share data rather than repeat tests.
- Increasing patient expectations of sharing data.
- Will require knowledge of information exchange standards (**IHE XDS**).
- Work with other specialties so you do not duplicate work and create confusing interaction point for other institutions.
Security model for how an institution will share data with “Personal Health Records” in a way that properly protects patient rights still not resolved.

26.3.4 Scope

- Understanding and agreeing on the scope of your enterprise plan is important.
- Define system expectations – volumes, performance, functionality.
- You should project the likely advances in the field, and increased expectations due to these advances. Then multiply by the square of the number of years the project is expected to last, divided by 5.

26.3.5 Buy-In

- In the first step, you should have identified all people critical to success. Are they on-board?
- Is that list still correct? As the plan was fleshed out, have new dependencies appeared?

26.4 Executing the Plan

26.4.1 The Plan Must Have Measurable Milestones

When the long-range plan is done, one should next develop milestones at reasonable intervals along the way. Intervals of 60–90 days are commonly viewed as optimal for operational teams.

Strategic planning is a key component of a successful healthcare enterprise, but more important is developing a plan that allows for identification of problems as (better yet: before) they arise, and provides tools and pathways for addressing problems before they become too large.

26.4.2 Contingencies

No project is immune to problems – they WILL happen.

- If you fail to ask the tough questions early, you will be asked tougher questions later on.
Project leaders must create an environment where team members feel comfortable raising concerns about the project status when appropriate.

Define a process that encourages team members raising concerns early.

Track progress on those concerns – sometimes no specific action is required beyond monitoring.

Ask for a review from outsiders – they can provide valuable objective impressions.

This is not to say that pessimism or negativity is the best policy – extreme pessimism will create an environment in which no project will be approved because of the lack of an apparent benefit.

26.4.3 Communications

- Make sure that all the people critical to success get regular updates on milestones.
- If things are not going well, a personal visit is warranted.
- Touch the right part of the administrative ladder. If you step over certain “touch points,” you may get backlash if some feel they were not properly notified in a timely manner.
- Consider using blogs or wikis to give people access to historical aspects of the project – why were certain decisions made and what were the problems that the project has faced?

26.4.4 End Points

A strategic plan may not always have clearly defined endpoints. That, in and of itself, does not mean the plan is bad – just that it is incomplete. Strategies by definition focus on how, rather than on what. The goal is the “what” and the strategy usually follows the goal.

When things go well

- It is very tempting to expand a successful project to include new ideas; resist this urge – exceptions should be exceptional.
- It is better to end the plan early due to success or changes in strategy than to morph a plan into something that confuses those who execute it.

Key Concept 26.8: Questions Are Key

Too many projects have been killed by overly optimistic assumptions and team kindness. Be tough but fair.
• **Plan the acceptance test before the rest.** It will guide the detailed requirements, the precise scope, and help assure adequate resources and time to make sure you are getting what you expected.

• **The project succeeded.** No large project is a one-person effort. Credit all team members for their contributions. Good leaders will recognize the roles of everyone on the team.

• **Do a de-brief.** Learn what went well and what did not for the next time.

In some cases, success is not an option. Ending a project without success is not pleasant, but is sometimes necessary. In cases where you must declare failure

• **Do not** look for whom to blame.

• **Do** look for why and how things went wrong so you and others do not do it again.

• **Talk** with team members and your leaders to understand their perspective on what went well and what did not.

• **The project failed – you did not.** Learn from it and move on. Life is too short to saddle yourself with more problems.

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**Pearls 26.9**

- Define (personal, team, business) goals and make sure the team agrees.
- Work hard to incorporate standards. It is always easier (in the short term) to do your own thing.
- Plan for “surprises”; look for them; identify them and address them before they become big problems.
- Define measurable milestones and adhere to them tenaciously.
- Do a post-mortem whether the project succeeds or fails – you will learn either way.

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**Suggested Reading**


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**Self-Assessment Questions**

1. Major components of a healthcare system architecture includes all but
   a. System
   b. Technical
c. Topographic
d. Information
e. Physical

2. Good project management should include all but
   a. Frequent team meetings
   b. Project management software
   c. Frequent adjustment of schedules to match achievements
   d. Communications with oversight groups/individuals
   e. Occasional external reviews

3. Scope creep includes all of the following except
   a. Trading some functionality for other functionality
   b. Adding functionality that can be accomplished within the contingency
   c. Adding a subsequent phase for addressing the needs of other facilities
   d. Adopting a new information model that better meets the plan
   e. Changing the standard video display card for PACS workstations

4. The earliest step in developing the plan among those listed below should be
   a. Defining the acceptance test
   b. Defining the detailed functionality requirements
   c. Selecting the hardware and software to be used
   d. Deciding who will agree that the final payment should be made
Answer Key

Chapter 1: Medical Imaging Modalities and Digital Images

1. d
2. b
3. b
4. d
5. a

Chapter 2: Computers and Networking

1. e
2. c
3. b
4. c
5. b
6. e
7. c
8. d
9. b
10. a

Chapter 3: Introduction to PACS

1. a
2. d
3. a
4. b
5. a
6. d
7. d
8. c
Chapter 4: Modalities and Data Acquisition

1. e
2. d
3. e
4. a
5. d
6. b
7. c
8. c
9. b
10. a
11. d
12. d
13. b
14. a

Chapter 5: Workflow Steps in Radiology

1. a
2. d
3. b
4. d
5. a

Chapter 6: Standards and Interoperability

1. ANSI (www.ansi.org).
2. Internet Engineering Task Force (www.ietf.org); World Wide Web Consortium (www.w3c.org).
4. DICOM Part 2, “Conformance.”
5. A: called application entity title (AE Title), IP address, DICOM port number; B: calling application entity title (AE Title), IP address, DICOM port number.
6. DICOM, Part 3, “information object definitions.”
7. You should look first into your HL7 message passing engine if you have one.
8. Integrating the Healthcare Enterprise (IHE), IT infrastructure technical framework.
9. Integrating the Healthcare Enterprise (IHE), IT radiology technical framework, mammography image integration profile.
10. IHE integration statement.
Chapter 7: Viewing Images

1. c. One of the main uses of compression of any kind (lossy or lossless) is to speed up transmission of data.
2. d. Spatial resolution is needed to discern fine details, contrast resolution is needed for visual acuity, and color vision is required in medical image areas that use color images (i.e. pathology).
3. c. Visual acuity and contrast sensitivity indicate that 2.5 cycles/mm or 200 micron pixel size is best.
4. a. HDTV is a broadcasting standard for television. The SPMTE was also developed for television and was used in radiology before the development of DICOM but is no longer recommended.
5. c. A moderate amount of light is recommended for viewing rather than too dark or too bright.
6. b. The inherent resolution of digital mammography images is high and exceeds the display resolution of small matrix displays. To avoid extended use of zooming to access the high resolution data and to view the entire image as close to full resolution as possible, a large matrix display should be used for mammography.
7. a. Contrast perception is important for discriminating subtle shades of gray between lesions and background.
8. b. Psychophysical studies have shown that a ratio of 50 is best.
9. Include but not limited to ambient lighting, chair selection, mouse/trackball selection, monitor height, room noise, airflow.
10. Include but not limited to window/level, zoom/pan, measurement tool.

Chapter 8: Image Postprocessing and Volume Rendering

1. b
2. c
3. a and c
4. d
5. c
6. b
7. b

Chapter 9: Image Distribution

1. d
2. Flexibility, Performance, Scalability, Cost-effectiveness, Integration to EHR, Security
3. c
4. d
5. Frequently make patient management decisions based on their interpretation of the image; frequently demand and require full-fidelity/diagnostic-quality images; also demand rapid (“near real time”) delivery of images, including relevant priors; usually still constrained by existing network and personal computer infrastructure.

6. d

7. Able to deliver via the web client all images that reside within the PACS archive; no prefetch or persistence logic is required; the enterprise user can be given a complete, comprehensive view of the patient’s medical image history; with some vendors, the enterprise user also shares a common view with respect to annotations, presentation states, etc.

8. (A) The PDI Profile guarantees that the CD/DVD will have a DICOMDIR and DICOM part 10 image; this will enable the import and export of images using CD/DVD portable media. (B) The Profile for Import Reconciliation Workflow (IRWF) provides the ability to efficiently reconcile imported image datasets by matching external identifiers with local identifiers (e.g., medical record number, accession number).

Chapter 10: Reporting and Dictation

1. c
2. b
3. c
4. b
5. d
6. c

Chapter 11: Customer Relations

1. e
2. b
3. b
4. c
5. c
6. Open-source software
7. The IIP can recognize problems before users even notice there is a problem
8. Proactive Monitoring of entire system
9. Automatic ways for email reminders for forgotten passwords or a 24/7 help desk.
10. Visit community medical association meetings as a guest speaker, attend staff meetings for other practices or departments, and publish newsletters and blogs with tips for better viewing and access to images.
Chapter 12: User Training

1. c
2. a
3. b
4. c
5. d
6. d
7. Needs assessment, program design using sound educational principles, program implementation according to design, evaluation of effectiveness.
8. Objectives are used as a means to determine the material covered in the training program as well as a guideline for evaluation of the effectiveness of the training.

Chapter 13: Quality Assurance for Medical Imaging

1. d
2. a
3. a
4. b
5. e

Chapter 14: Data Storage and Disaster Recovery

1. d
2. c
3. a
4. b
5. d
6. a
7. d
8. b
9. a & d
10. c
11. d

Chapter 15: Downtime Procedures and Departmental Policies

1. c
2. d
3. d
4. e
5. a
7. A single copy of image data on a single server in only one location.
8. The time needed to change personnel tasks and possibly applications and/or systems at the start of a downtime may take longer than the actual downtime.

Chapter 16: Reading Room Design

1. c
2. d
3. a
4. d
5. e
6. d
7. d
8. d
9. a

Chapter 17: Workflow Testing and Workflow Engineering

1. a
2. b
3. d
4. c
5. d

Chapter 18: Policy Management and Regulatory Compliance

1. d
2. c
3. a
4. c
5. b
6. d
7. c
8. c
9. d
10. b
Chapter 19: Billing and Coding

1. Like a social security number, a medical record number (MRN) is intended to uniquely identify a patient, and to resolve the problem of two patients with the same name. MRN is intended for use only within a hospital system. A single patient may have multiple MRNs if they move from one hospital system to another.

2. CPT codes describe procedures and methods; ICD9 codes describe symptoms and diseases. Both are needed for appropriate coding (see section 19.3).

3. See section 19.3 for the formats of CPT and ICD9 codes.

4. Patient name; patient date of birth; facility name; date of service; department code; type of study; body part(s); number of views; administration of contrast; patient history; diagnosis

Chapter 20: Economics of PACS and Related Systems

1. e
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Chapter 21: PACS Readiness

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Chapter 25: Team Building and Project Management

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Chapter 26: Long-Range Planning

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Glossary

Note: The glossary includes terms that are defined in this book. The number in brackets following each entry indicates in which chapter the definition can be found.

AAPM TG-18 – the American Association of Physicist in Medicine, Imaging Informatics Subcommittee Task Group #18. [23]

Advanced Visualization System – Workstations primarily used for post-processing of medical images such as 3D renderings. [15]

Affinity Domain – “An IHE Affinity Domain is a group of healthcare enterprises that have agreed to work together using a common set of policies and share a common infrastructure.”


AJAX – Asynchronous JavaScript and XML. A group of popular web methods used to create interactive web browser-based applications. [9]

Artifact – Any component of the image that is extraneous to the representation of tissue structures; can be caused by a technique, technology, hardware, or software error. [1]

ASP – Application Service Provider (ASP) is a fiscal model for PACS in which the vendor owns, operates, and supports the PACS software. This minimizes support costs but provides no ownership investment. [22]

Asynchronous Communication – Two workers communicate asynchronously when they do not need to be simultaneously available. Thus, each worker can integrate the data into their workflow more efficiently. Email is the most familiar example of asynchronous communication. [17]

Authentic Assessment – Evaluation of learning based on real-work tasks. [12]

AutoRouting – The automatic transmission (“routing”) of image datasets from the modalities to remote destinations based on predefined rules (e.g.,
“autoroute all abdomen CT exams to the abdomen reading room workstations”). [9]

**Bandwidth** – The maximum amount of data that can be transmitted over a medium, usually measured in bits per second. [2]

**Base Case** – The most frequent task that is performed. Workflow design should address the base case first and foremost, even if less frequently utilized workflows are made less efficient. [17]

**BI-RADS** – Breast Imaging – Reporting and Data System is a QA tool for mammography reporting. [18]

**BI-RADS Assessment Categories:**

0 – Incomplete
1 – Negative
2 – Benign
3 – Probably Benign
4 – Suspicious Abnormality
5 – Highly Suggestive of Malignancy
6 – Known Biopsy – Proven Malignancy

**CCOW** – Clinical Context Object Workgroup. HL7 standard protocol that enables different applications to be synchronized and share context. Can be used to achieve “single-logon” of multiple applications. Prevents the user from having to retype information when moving between information systems. [9]

**Classification** – The assignment of a meaningful name like “lung” to a group of pixels or voxels. [8]

**Compression** – Compression reduces the volume of data to reduce image processing, transmission times, bandwidth requirements, and storage needs.

*Lossless compression* allows for reconstruction of exact original data before compression without loss of information.

*Lossy compression* uses methods that lose data once the image has been compressed and uncompressed. [7]

**Computed Tomography** – An x-ray imaging procedure acquires thin-slice projection data using a rotating x-ray tube and detector array, and then produces many tomographic images of the anatomical volume by computer reconstruction algorithms. [4]

**Connect-a-thon** – A vendor neutral, monitored and controlled, testing event where vendors can test their systems IHE interoperability with other vendors. [6]

**Convolution** – The multiplication of a neighborhood of pixels by a “kernel.” Each value in the kernel is the number by which the corresponding neighborhood pixel is multiplied. If all the values in the kernel are “1,” the result is the mean. [8]
CPOE – Computerized Provider Order Entry. [20]

CPT – CPT codes are used to precisely classify medical, surgical, and diagnostic services and procedures. The CPT code tells what was done; the ICD9 code tells why it was done. [19]

Dashboard Display – A graphical interface that summarizes input from many sources into a small visual area that can be quickly understood. More detailed information is available by expanding individual elements of the dashboard. [17]

Database – A structured collection of data. Data that are housed in a database is more amenable to analysis and organization. Databases are ubiquitous and are the essential component of nearly every computer application that manages information. [2]

DGSF – Departmental gross square feet [or meters] = sum total of all the NSF allocations within a department plus the area accommodating wall thicknesses, permanent building structures, and departmental corridors. NSF multiplied by a “net-to-gross” multiplier (typically ranging from 1.40–1.65 for a radiology dept.) yields DGSF. [16]

DICOM – Digital Imaging and Communication in Medicine is the standard format for PACS files and messages. [3]

DICOM Conformant – the equipment includes a DICOM interface and a Conformance Statement is available that describes the particulars of the DICOM implementation. [21]

DICOM Data Element – A DICOM data element is the smallest unit of information in a DICOM Information Object. Each data element has a tag that consists of a group number and an element number usually shown in hexadecimal and in parentheses, e.g., (XXXX, YYYY). Each data element has a value representation (VR) that defines what kind of data it is. Each data element also has a value multiplicity (VM) that specifies whether the element can contain multiple values and if so, how many. [6]

DICOM Ready – the equipment does not include a DICOM interface, but one is available as an option. [21]

DICOM Service – A DICOM service is a specific set of operations to be performed. For example, the DICOM Storage Service class defines the operations necessary to facilitate the transfer of DICOM objects from one system to another. [6]

Digital Dashboard – A graphical interface that summarizes input from many sources into a small visual area that can be quickly understood. [11]

Doppler Ultrasound – A technique to examine moving objects in the body. Blood flow velocities can be measured using the principle of a shift in reflected
sound frequency produced by the moving objects. Can be used to image the cardiac chambers and valves of the heart, arterial flow, particularly to assess the carotids and peripheral vascular disease, and venous flow studies for the detection of deep-vein thrombosis. [1]

**Dynamic Transfer Syntax (DTS)** – An example of a “just in time” data delivery mechanism designed to efficiently use constrained network bandwidth without the use of quantization-based (lossy) image compression. [9]

**EHR** – Electronic Health Record. [20]

**EMR** – Electronic Medical Record. [20]

**Escalation Policy** – The first point of contact (either the vendor’s or yours!) may not respond in a timely fashion. Who do you contact next? Who do you contact if that person fails to respond? This sequence of individuals is an escalation policy. [15]

**Exception** – Image whose patient demographic and exam information disagrees with the RIS. [13]

**Fat Finger Error** – Manual typing is inherently error-prone, especially when the data are numerical. Fat-finger errors are typographical errors that could be avoided by pre-populating data fields. [17]

**Filter** – A processing method that enhances or removes a specific component in a signal or image. The name could reflect what is removed, what is enhanced, or the calculation that is used. [8]

**Flag** – Reminder or indicator that new data are available. Usually, an auditory or visual cue within a software program. Example: “You have mail!” [17]

**Fluoroscopy** – A “real-time” x-ray projection image acquisition sequence used for dynamic evaluation of many patient procedures in diagnostic and interventional radiology. [4]

**Fourier Transform** – A Fourier transform converts an image from spatial domain (e.g., there is a specific distance between the centers of pixels) to the frequency domain (each location in an image represents frequency components in an image). [8]

**Heavy Iron Workstation** – A high-end, expensive client computer. It is possible to deploy these across the radiology department, but prohibitively expensive for the entire enterprise. [9]

**Histogram** – A graph that reflects how many pixels of each brightness are on the image. The horizontal axis is brightness, and the vertical axis is number of pixels. [8]

**HL7** – HL7 is a standard ubiquitous in the non-PACS healthcare information system world. This includes most hospital and radiology information systems.
Like DICOM, HL7 is a standard, though quite different from DICOM. It is aimed chiefly at sending messages between systems to carry non-image information. Most interfaces to hospital and radiology information systems use HL7. HL7 used to be an acronym, standing for “health level 7” and referring to the application layer of a communications model. However, HL7 is now a name, not an acronym. To communicate between an RIS and PACS, HL7 messages from the RIS will likely have to be “translated” into DICOM and from DICOM into HL7 if information has to go back to the RIS from the PACS. This translation is often done with a computer known as a “broker.” [21]

**Hounsfield Unit** – CT number representing absorption values of tissues; expressed on a scale of +1000 units for the maximum X-ray beam absorption of bone to –1000 units for the least absorbent air. Water is used as a reference material for determining CT numbers and is, by definition, equal to 0. [1]

**ICD9** – ICD9 codes are used to classify medical diseases and a wide variety of signs, symptoms, abnormal findings, complaints, social circumstances, and external causes of injury or disease. [19]

**IHE** – Integrating the Healthcare Enterprise is an initiative that has created a framework for medical workflow by which different electronic information systems can exchange information. [5]

**IHE Actors** – IHE actors define units of functionality that are required to get a particular job done in a particular integration profile. Note that any given commercial information system may provide no, single, or multiple IHE actor functionality. [6]

**Incident Report** – Post-downtime report provided by the vendor explaining the cause of any unscheduled downtime. [15]

**Information Entity** – An information entity represents a real-world entity. The “Patient IE” is an information entity that represents the real-world patient. [6]

**Information Object Definition** – An information object definition is a data model of a real-world object. For example, the DICOM computed tomography (CT) information object definition is a model of all the information contained in a CT study. [6]

**Integration Profile** – A specific problem of healthcare interoperability AND the details of the standards based, proposed IHE solution. [6]

**Interoperability** – The ability of an information system to participate in a complex information management process in a concerted fashion with a number of other information systems. [6]

**IOD** – A DICOM Information Object Definition is an idealized functional representation of a real-world object. It often contains more attributes than the real-world object it represents. [4]
**Ionizing Radiation** — Radiation capable of producing energetic charged particles that move through space from one object to another where the energy is absorbed; may be hazardous if used improperly. [1]

**Isotropic** — Having the same size in each dimension. [8]

**Isotropic Dataset** — Traditional CT images have much greater resolution in the plane of imaging (usually transverse or “axial” plane). Multidetector CT can produce data with the same high resolution in the orthogonal direction, called an isotropic (or volumetric) dataset. These studies are of much greater size than traditional studies. [9]

**Learning Management System** — System that supports the delivery, tracking, and management of training resources and user evaluation. [12]

**Legacy Device** — Old equipment purchased before new standards were widespread. Often requires upgraded interfaces to communicate with modern PACS. [4]

**Lexicon** — A related set or collection of terms, labels or entities. [10]

**Limited Persistence Cache** — Image storage (separate from the main PACS archive) where image studies are stored for only a limited (not permanent) amount of time. [9]

**Lookup Table** — A lookup table converts the pixel values of an image into brightness values for the display. Lookup tables are defined for each display monitor individually, so they can be used to ensure that an image looks exactly the same on every display. [13]

**Lossless Compression** — Digital data compression in which all the original data information is preserved and can be completely reconstituted. [14]

**Lossy Compression** — Methods of digital compression in which the original information cannot be completely reconstituted. [14]

**Macros and Templates** — Predefined reports, words, phrases, or other data that are used to shorten reporting time. These can consist of an entire report and often are created with blanks that can be filled in with other data such as numerical values. Some distinguish between a macro, a complete stored report versus a template, a report created with blank fields for the easy insertion of other data elements, numerical or otherwise. [10]

**Master Patient Index** — The MPI, also known as the Enterprise Patient Index (EPI) is a multi-institutional database that allows reliable identification of a patient, as well as access to other identities the patient may have at other sites. Allows exams from multiple sites to coexist in a single PACS. [3]

**Medical Coding** — The area of healthcare that focuses on accurately and efficiently completing the patient’s paperwork so that it may be submitted to the insurance carrier for reimbursement. [19]
MIRTH – MIRTH (www.mirthproject.org) is a powerful, free, open source, multiplatform, HL7 interface engine. [6]

Modality – May refer to a specific machine that acquires images (e.g., CT scanner #3), or a class of machines that use the same basic technology (e.g., Modality = CT). [3]

Modality Interfacing [4]

- **Source AE (Application Entity) title**: a unique name that identifies the specific modality to the PACS.
- **Target AE title**: a name that identifies the PACS (e.g., image storage) to the modality. For a given IP address and port number, the AE title must be unique.
- **IP address**: unique static address assigned to the modality client and the PACS server; IP addresses are used for transmission of image and patient demographic information from the client to the server over an electronic network with TCP/IP (Transmission Control Protocol/Internet Protocol).
- **Port number**: specific port assignment to allow communication from a specific starting point on the client to a specific endpoint on the server; the IP address and the port number comprise a communication socket.
- **Modality Worklist (MWL) interface**: provides patient demographic and procedural information (type of study) from the scheduling module (e.g., Radiology Information System) to the modality console through a PACS “broker” that translates HL7 (Health Level 7) messages into compatible DICOM information.

MP – MP refers to “mega pixels” or the number of pixels contained in the display. [7]

MRI – Magnetic resonance is an imaging procedure that uses a strong magnetic field (1.5–3 Tesla) to magnetize protons in the tissues of the body. Radio frequency excitation of the protons results in energy absorption and subsequent re-emission of RF signals, which are detected and processed to reveal the magnetic characteristics of tissues in terms of a grayscale image. Pulse sequences specifically generate tissue contrast differences; typically, several sequences are acquired for a specific MRI study. [4]

Nighthawk – Generic term indicating preliminary or final interpretations provided on overnight and weekend cases. The “nighthawk radiologist” is usually located in a different time zone, and uses networking to get images to read within a few minutes, and faxing out preliminary reports to radiology departments and emergency departments. This function is widely used by most hospitals in the US, particularly those that are too small to have radiologists provide 24 × 7 onsite service. [3]

Noise – Random fluctuations in the image information that can obscure the true elements in the image. Noise reduction is also called improving the signal-to-noise ratio. [8]
NSF – Net square feet = Space allocation excluding fixed walls, corridors, or permanent building structure. [16]

Nuclear Medicine and Molecular Imaging – Nuclear medicine imaging uses tracers tagged with radioactive materials that are injected into the patient and are redistributed according to metabolic activity. “Emission” images are created from the localization of the recorded activity acquired over a period of time (typically minutes to hours) with a device known as a scintillation camera. In many studies, image sequences are generated as a function of time (e.g., first-pass bolus tracking, gated cardiac imaging). [4]

Ontology – A domain that formally defines a set of classes of terms (“entities”), attributes of those terms (“slots”) and relationships of the terms. [10]

Opacity – A measure for how transparent a voxel is, ranging between 0 and 1. [8]

Out of Band Task – A task that is not part of the routine workflow, and must instead be performed while normal workflow is suspended. Workers often neglect out-of-band tasks. [17]

Over-reading – Radiology trainees (residents) need and deserve feedback on the preliminary readings they provide when staff (attending radiologist) is not present, commonly overnight or weekend situations. This can be provided by attending physically sitting down with the resident, but this is sometimes impractical. PACS allows the attending to review or “over-read” the on-call exam and the attached reading, and to provide “grading” and feedback, using mechanism similar to peer review. [3]

PACS – A Picture Archiving and Communication System stores, distributes, and displays medical images for interpretation or review. [3]

PACS Database – For PACS, the pertinent data elements included in the database are the patient demographics, associated reports, study description, where the images were obtained, and where the images are stored. [3]

PACS Broker – Software that converts and translates between HL7 messages (for the HIS or RIS) and DICOM transactions (for the PACS). [3]

PET – Positron Emission Tomography uses cyclotron-produced positron-emitting isotopes including oxygen, carbon, nitrogen, and fluorine enabling accurate studies of blood flow and metabolism; positron isotopes are short-lived positively charged electrons; main clinical applications are in the brain, heart, and tumors. [1]

PHI – Protected Health Information. Any health information that is specific to an individual and can be identified to the individual. There are 18 specific identifiers listed in HIPAA. [18]

Pipeline – A sequence of stages that performs a task in several steps, like an assembly line in a factory. Each stage takes inputs and produces outputs that are stored in its output buffer. One stage’s output is the next stages input. [8]
Prefetch – The automatic delivery of image datasets from the archive to designated workstations based on predefined rules (e.g., “prefetch all relevant prior chest CT exams to the chest reading room workstations”). [9]

Project Management – The discipline to plan, organize, and manage resources to provide optimal project outcome. [25]

Quality Assurance and Quality Control – Quality Assurance (QA) is the overarching program that asks the question, “Are we operating the devices correctly?” A subset of QA is Quality Control (QC) that asks the question, “Are the devices operating correctly?” Certainly, optimal QA requires optimal QC, but often overlooked is the human element, since imperfect operation of a technically optimal system will result in substandard image outcomes. Continuous quality improvement is a key factor for acting on QA and QC findings to strive for optimal patient care. [4]

Quality Assurance (QA) – All activities that seek to ensure consistent, maximum performance from the physician and imaging facilities. [13]

Quality Control (QC) – Activities that generate data indicating the current state of quality in the department. [13]

Radiography – This imaging procedure uses a uniform beam of x-rays incident on the patient, which are modulated by the tissues, and subsequently detected and converted into a two-dimensional grayscale image by the x-ray detector. Benefits include a rapid and inexpensive acquisition capability; difficulties include super-imposition of anatomy that can hide findings or mimic disease processes. [4]

Reading Room/Reading Area – Defined space containing one or more work areas. [16]

Registration – The process of aligning images with one another. This means that the same tissue sample exists at a given X, Y, Z location on all registered images. [8]

Reject – An image that is not useful for care of the patient. Includes test images and non-diagnostic images. [13]

Repeat – Duplicate image obtained because original image was substandard or lost. [13]

Request for Information (RFI) – A document delivered to vendors as part of a product selection process. The document describes attributes necessary to be included in a Request for Proposal. These attributes can vary but typically include information about the company, product portfolio, and experience in the relevant field. Based on the results of an RFP, a customer will decide whether to include the vendor in the product selection process. [24]

Request For Proposal (RFP) – Document distributed to vendors to solicit information related to the acquisition of a product or service. The RFP may
request information related to the company, product, service offering, and pricing for a product of interest. The document will also provide specific information about the organization evaluating the technology, including facilities, volume, technology infrastructure, and workflow. An RFP will also provide logistics related to the timing and format of responses. [24]

**Residents and Attendings** – Apprentice radiologists, having completed medical school and now specializing in radiology, are generically called “trainees” or “housestaff.” They are divided into residents (more junior) and fellows (more senior). The interpretations rendered by trainees must be overseen by board-certified (“attending” or “staff”) radiologists. [3]

**Retention Period** – Time, mandated by federal, state or local statute, that medical information must be retained in its original and legal form. [14]

**RIS** – The Radiology Information System is software that manages the day-to-day operations of a Radiology Department, or group of cooperating Radiology Departments. Can receive orders from the Hospital Information System, or allow manual input of orders locally. Messages outbound to PACS Broker use HL7 format. [3]

**RSS Feed** – Really Simple Syndication allows users to automatically receive the latest updates of a blog or website without having to directly visit the site. [11]

**Run Chart** – A graphing model that plots a known variable over time. [25]

**Segmentation** – The separation of an image into meaningful components. In most medical applications, this refers to an anatomic structure (e.g., a blood vessel, bone, lung) or a disease process (e.g., a tumor). [8]

**Self-Edit Mode** – Users dictate, edit, and sign reports without the aid of back-end human transcription. Reports can be completed one at a time or batched. [10]

**Server–Client** – A server is a computer that provides application services or data. A client is a computer or software application that receives those services and data. [2]

**Similarity Metrics** – Quantitative measures of how well two images are matched. They are an essential element of image registration. [8]

**Single Point of Failure** – If failure of a single piece of software or hardware can cause the entire system to stop functioning, this is a single point of failure. Single points of failure are dangerous, and are combated with redundancy. [15]

**Site Visit** – During the vendor evaluation process, a group of key stakeholders will travel to another institution (the “show site”) that already uses the product, to observe the product in a live environment. [24]

**Six Sigma** – A systematic method for preventing errors in service-related processes by using information and statistical analysis. Six Sigma relies on
uniform workflow, which limits its applicability to physicians with idiosyncratic workflow. [17]

**SPECT**  – Single-Photon Emission Computed Tomography; a tomographic slice is reconstructed from photons emitted by the radioisotope in a nuclear medicine study. [1]

**Speech Recognition**  – A software application that automatically converts spoken words into text. SR replaces a medical transcriptionist. [10]

**Strategic Planning**  – Planning that occurs prior to receiving approval and budget to proceed. [26]

**Structured Reporting**  – There is some confusion as to the exact definition of structured reporting. According to Dr. Curt Langlotz, it can be considered a three-pronged approach with three different features:

- Feature 1. A report that is consistent throughout with headings such as HISTORY; FINDING; IMPRESSION.
- Feature 2. A report that lists organ systems in an organized itemized fashion with prose or shorter descriptive terms following each heading. This type of report is sometimes called an itemized report.
- Feature 3. A report that uses a standard lexicon with all findings codified within the database for billing, indexed search, and data mining capability. [10]

**Supplemental Task Lighting**  – Additional local lighting that enables manual tasks such as writing and paperwork without disturbing other room occupants. [16]

**Tactical Planning**  – Planning and adjustments that occur after the point of project approval. [26]

**Task Allocation Matrix**  – A chart listing QC tasks indicating who is responsible for doing them and the frequency that they are performed. [13]

**Technical Framework**  – A collection of Integration Profiles of a given Domain. [6]

**Thick Clients**  – A thick client is a software application that completely “takes over” the operation of a workstation computer. While other applications may be run, the thick client typically has to be minimized or paused to allow such operation. All of the application’s power is in the thick client software; servers typically provide image data only. [21]

**Thin Client**  – A software application that does not depend upon any additional software components and does not perform any processing on the local host. [2]

**Thin Clients**  – A thin client is a software application that gains most of its power from a server. This is very much the way a web browser works.
The content of a web page as well as any interactive tools need only minimal software on the workstation; the server handles the tasks the user requests. [21]

**Thread Test** – Once each module in a complex system has been individually tested, sample data are passed from module to module to ensure that they link up appropriately. This is called a thread test. The passage of data should mirror true clinical workflow as closely as possible. [23]

**Transcriptionist Mode** – Users dictate in a conventional manner, and SR is applied. The text and wav file are then sent to a transcriptionist where corrections are made. A corrected draft report is returned to radiologist for final approval. [10]

**Transform** – A mapping from the space of one image to the space of another image. [8]

**Turnaround Time** – The time interval between the completion of a study and the study’s report becoming available in the medical record. [10]

**Turn Key Solution** – Some organizations prefer to have a single vendor provide everything required for the PACS. This model is referred to a “turn key.” Even if the vendor is responsible for everything, the vendor needs to provide a breakdown of the costs into the constituent categories. [20]

**Ultrasound (US)** – US generates tomographic images of the *acoustic properties* of body tissues by sending short, high frequency sound pulses into a specific volume, listening for echoes, and creating anatomic grayscale images. The evaluation of blood flow by Doppler signal analysis and/or color flow imaging are also important capabilities of US. [4]

**Vendor of Choice (VOC)** – When conducting an evaluation of technology, the VOC is preferred vendor of an institution based on initial information. “Due diligence” is the process of confirming that the VOC is the best choice for the institution. [24]

**Volume Rendering** – A visualization technique to display a 2D image of a 3D dataset that retains access to the original voxel data. Commonly referred to as a “3D reconstruction.” [8]

**VPN** – A virtual private network (VPN) provides data security for network elements that lie outside the physical enterprise. Data encryption and secure communications are critical to VPN. [25]

**Voxel** – A combination of the words volumetric and pixel, used to represent the basic element of a 3D volume dataset. [8]

**WADO** – Web Access to DICOM Persistent Objects. Defines a DICOM standard to access DICOM objects via the web. [9]

**Wet Read** – A brief preliminary interpretation rendered by the radiologist before taking the time to formally and completely review the images. In the film era, this report was rendered while the film was still wet from processing. [3]
**Wiki** – A page or collection of web pages designed to enable any user to contribute or modify content. [11]

**Work Area** – Zone including PACS monitors and computer system; one or several people seated or standing reviewing the same set of images and data (note: architects often refer to a workstation as being the same as a work area; radiologists often refer to a workstation specifically as the PACS equipment). [16]

**Workflow** – The steps that employees perform as they are getting their work done, and the relationships between those steps. [17]

**Workflow Bottleneck** – The most inefficient step in a process; the step that defines the maximum rate at which the entire process can proceed. [17]

**Workflow Token** – Reminder or indicator that a workflow task requires attention. Usually a physical object passed from one person to another. Examples: paper exam requisitions, typed dictations to be signed. [17]
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