Handout #12 Summary

Part I Summary of Medial Imaging Technologies

12.1 Comparison of major clinical modalities

12.2 Other medical imaging techniques

12.3 PACS and teleradiology: technologies to facilitate clinical practice

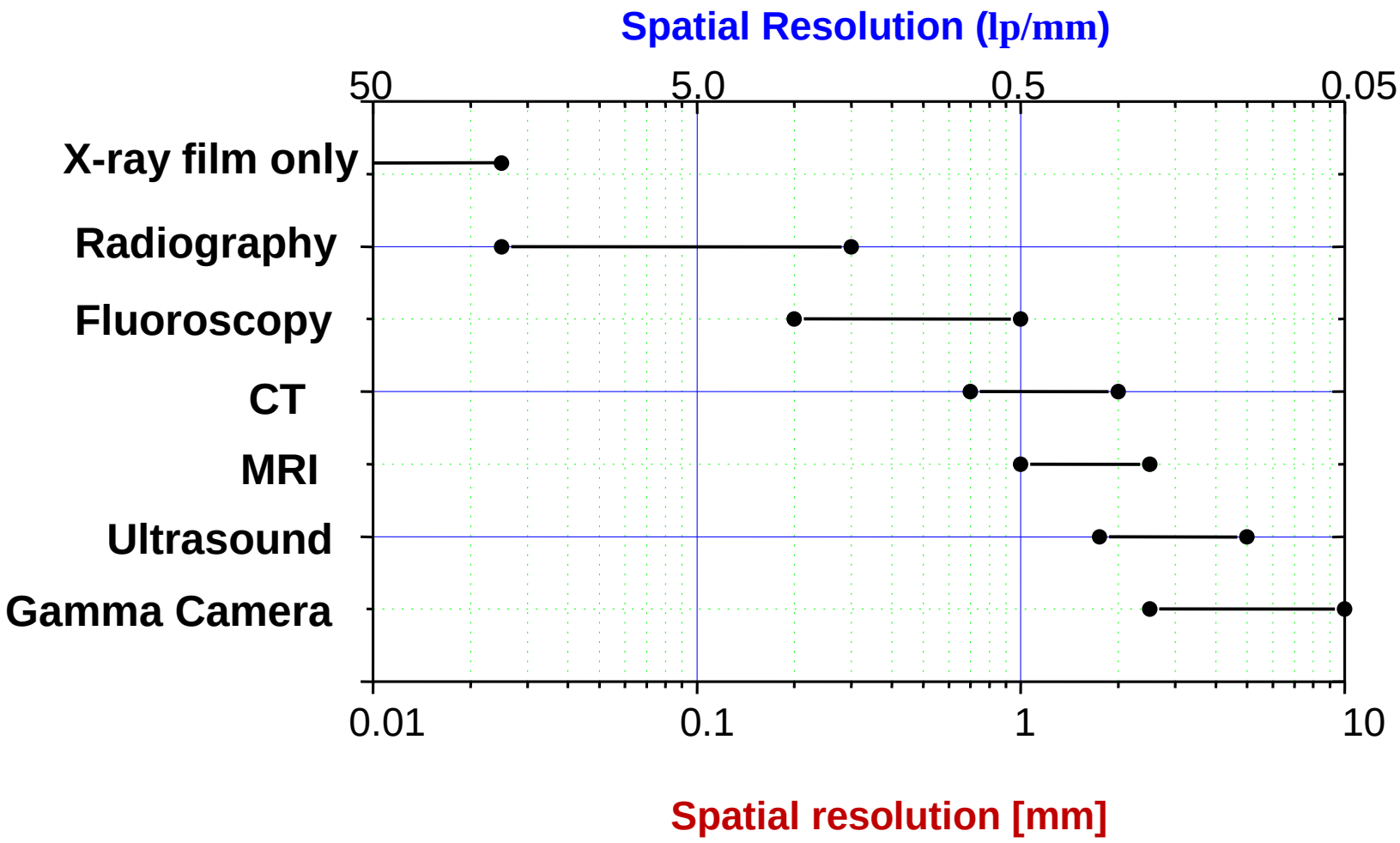
12.1 Comparison of Major Clinical Modalities

	Projection Radiography	Fluoroscopy	Computed Tomography	Nuclear Camera	MRI	Ultrasound
Source	X-ray	X-ray	X-ray	Gamma ray	Magnetic field + RF	Ultrasound wave
Source generator	X-ray tube	X-ray tube	X-ray tube	Isotope	Magnet + RF Coil	Transducer
Detector	Screen-film or 2D digital detector	II-TV or II-CCD	Electronic detector	Scintillation crystal+ PMT array	Receiver coil	Transducer
Measured parameter	$N_0 e^{-\mu x}$	$N_0 e^{-\mu x}$ DSA: μX	$P= \ln(Ni/N_0) =(\mu 1 + \mu 2 +\ldots)\Delta X$	Radioactivity (Number of events)	**MR signal	Echo US wave + time Doppler: freq shift
Image	2D	2D	Cross section slices--3D	2D or 3D	Cross section slices--3D	2D or 3D
Real time?	No	Yes	No	No	No	Yes
Nature of info	Mainly anatomy	Mainly anatomy	*Mainly anatomy	Function	Anatomy/ function	Anatomy/ function

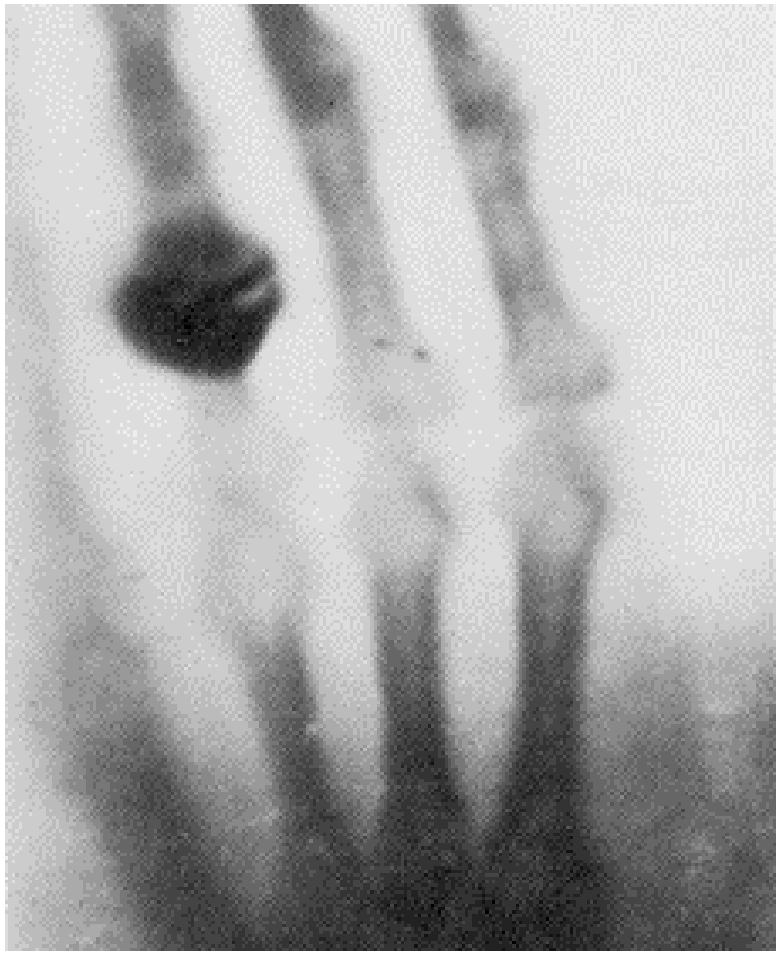
* Functional information may be acquired when contrast agents are used.

**An MRI system produces a MAP (throughout a part of the body situated in a strong magnetic field) of variations in the RELAXATION TIMES of the HYDROGEN NUCLEI in the WATER MOLECULES of the tissue. Those relaxation times depend on the types of tissues being imaged, and on their state of health.

Spatial resolution of commonly used clinical systems



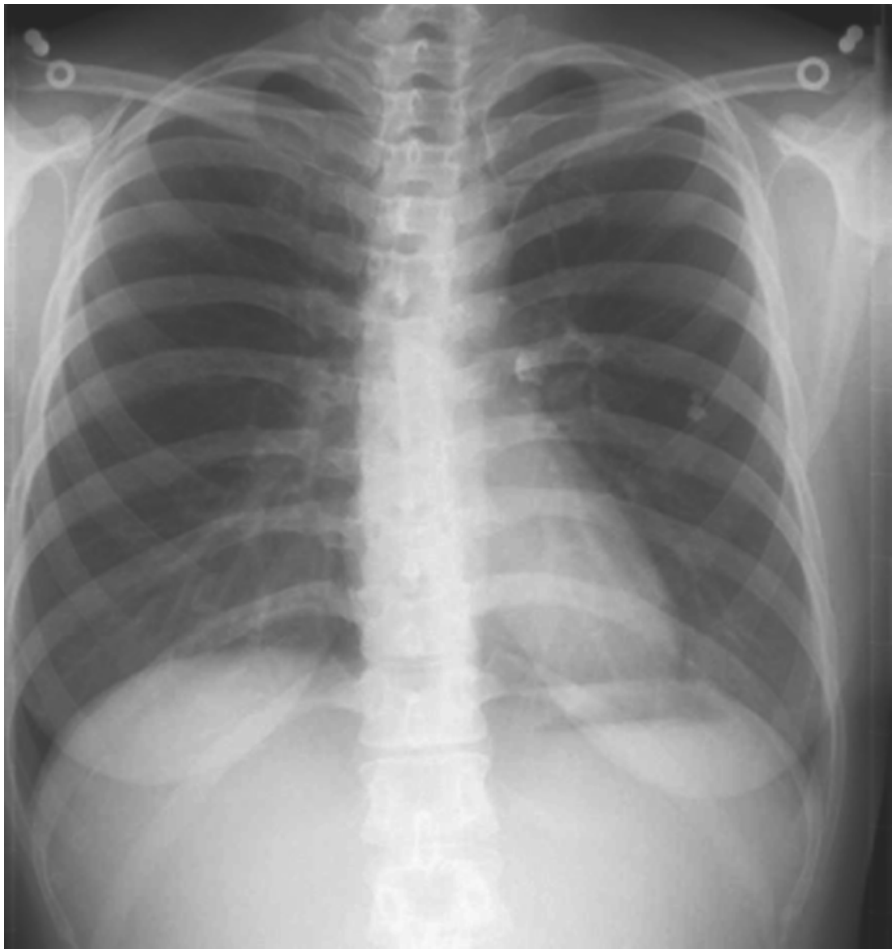
Some typical medical images



J.T. Bushberg, J.A. Seibert, E.M. Leidholdt, Jr., J.M. Boone, *The Essential Physics of Medical Imaging,2002*

First x-ray image

- The first radiographic image made on December 22, 1895 by Dr. Wilhelm Conrad Roentgen.
- Dr. Roentgen assigned the letter "x" to represent the unknown nature of the ray and thus the term x-ray was born.

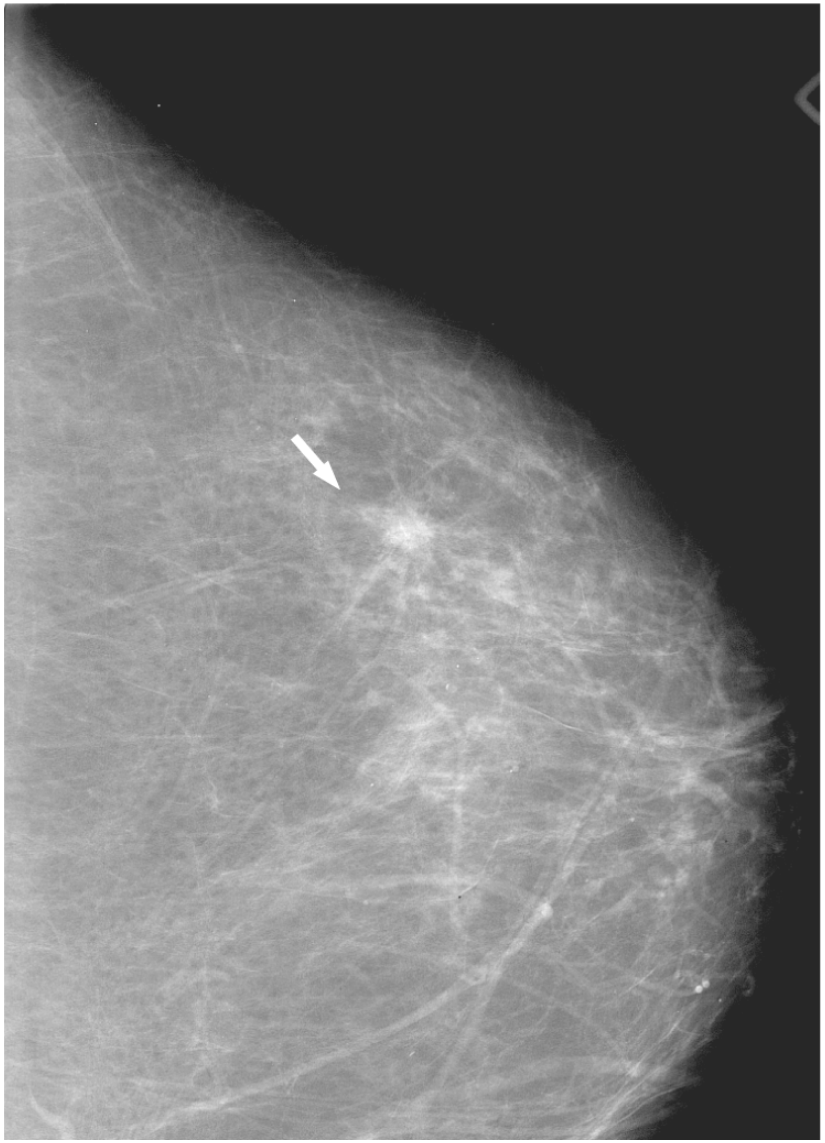


J.T. Bushberg, J.A. Seibert, E.M. Leidholdt, Jr., J.M. Boone, *The Essential Physics of Medical Imaging,2002*

Projection x-ray: chest

- The chest x-ray is the most ubiquitous image in diagnostic radiology.
- Rapid acquisition, low risk, low cost, and high diagnostic value are the major reasons why x-ray projection imaging represents the bulk of all diagnostic imaging studies.

Digital projection x-ray image



J.T. Bushberg, J.A. Seibert, E.M. Leidholdt, Jr., J.M. Boone, *The Essential Physics of Medical Imaging,2002*

Projection x-ray: mammogram

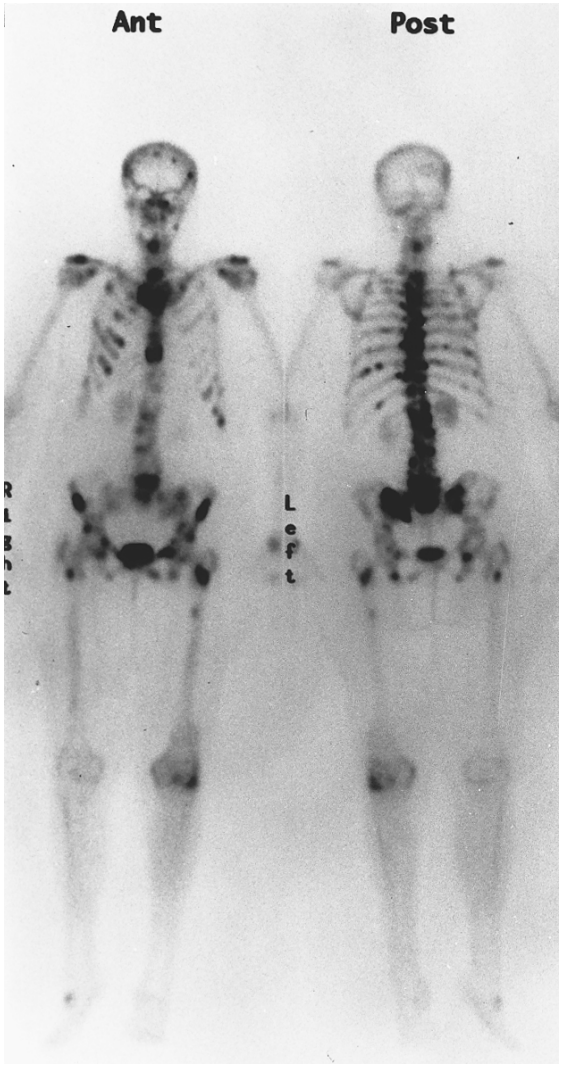
- Mammography is a specialized x-ray projection imaging technique for screening and early detection of breast cancer.

Computed tomography

J.T. Bushberg, J.A. Seibert, E.M. Leidholdt, Jr., J.M. Boone, *The Essential Physics of Medical Imaging,2002*

- A computed tomography, (CT) image of the abdomen reveals a ruptured disc (arrow) manifested as the bright area of the image adjacent to the vertebral column. Anatomic structures such as the kidneys, arteries, and intestines are clearly represented in the image.
- CT provides high-contrast sensitivity for soft tissue, bone, and air interfaces without superimposition of anatomy.

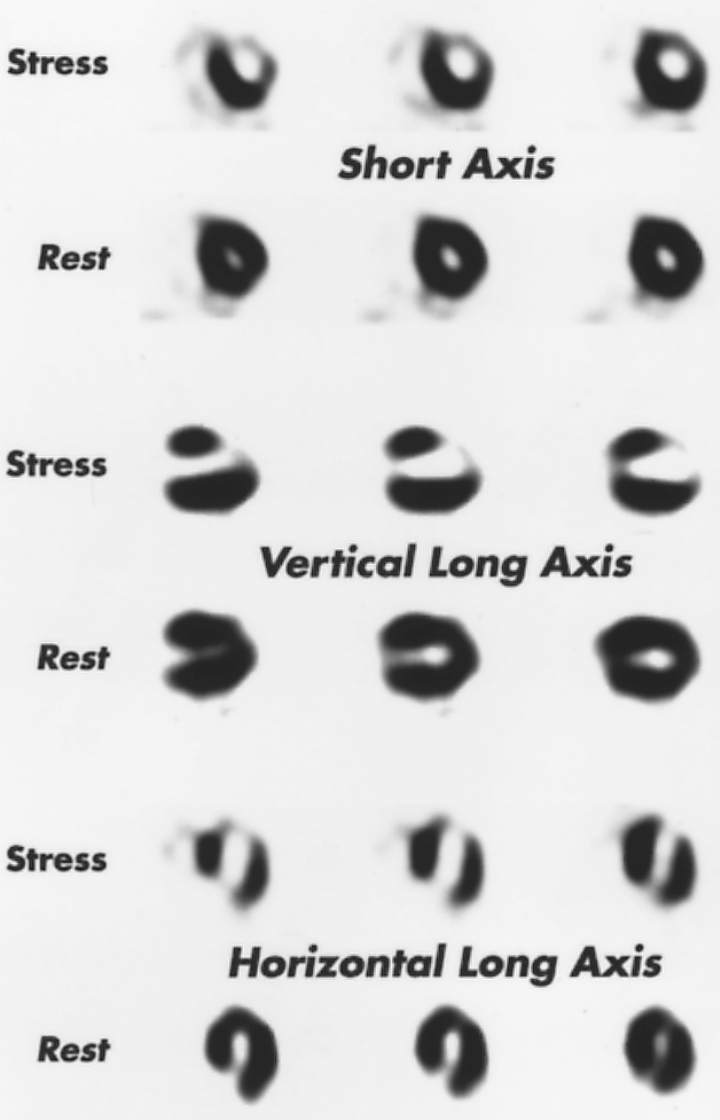
Radionuclide imaging



J.T. Bushberg, J.A. Seibert, E.M. Leidholdt, Jr., J.M. Boone, *The Essential Physics of Medical Imaging,2002*

- Anterior and posterior whole-body bone scan of a 74-year-old woman with a history of right breast cancer. This patient was injected with 925 MBq (25 mCi) of technetium (Tc) 99m methylenediphosphonate (MDP) and was imaged 3 hours later with a dual-headed whole-body scintillation camera.
- The scan demonstrates multiple areas of osteoblastic metastases in the axial and proximal skeleton. Incidental findings include an arthritis pattern in the shoulders and left knee.

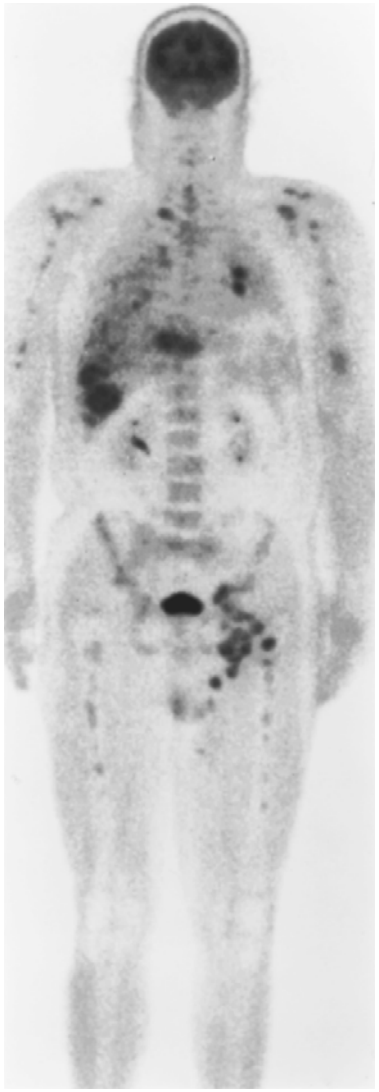
SPECT



J.T. Bushberg, J.A. Seibert, E.M. Leidholdt, Jr., J.M. Boone, *The Essential Physics of Medical Imaging,2002*

- A myocardial perfusion stress test utilizing thallium 201 (TI 201) and single photon emission computed tomography (SPECT) imaging was performed on a 79-year-old woman with chest pain.
- This patient had pharmacologic stress with dipyridamole and was injected with 111 MBq (3 mCi) of TI 201 at peak stress. Stress imaging followed immediately on a variable-angle two-headed SPECT camera.
- The rest/redistribution was done 3 hours later with a 37-MBq (1-mCi) booster injection of TI 201. Findings indicated coronary stenosis in the left anterior descending (LAD) coronary artery distribution.
- SPECT is now the standard for a number of nuclear medicine examinations including cardiac perfusion and brain and tumor imaging

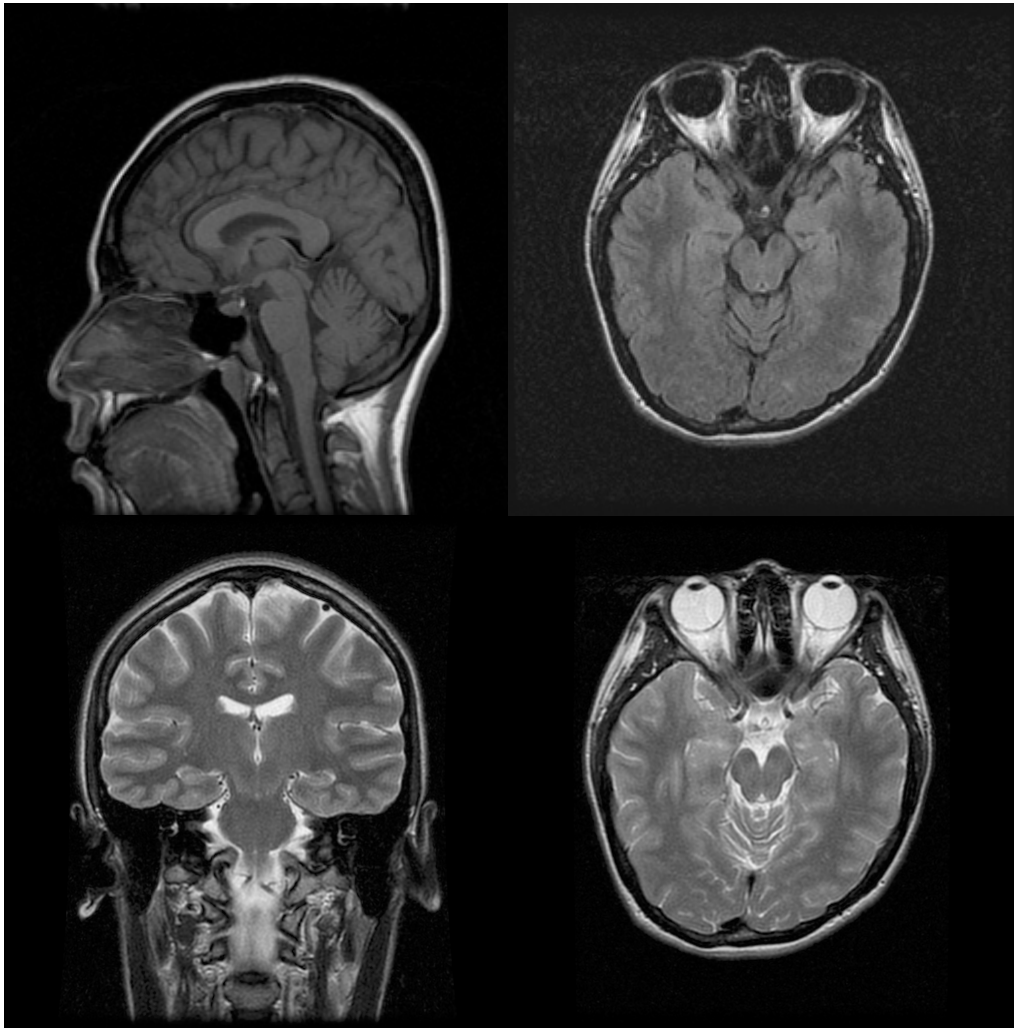
PET



J.T. Bushberg, J.A. Seibert, E.M. Leidholdt, Jr., J.M. Boone, *The Essential Physics of Medical Imaging,2002*

- Whole-body positron emission tomography (PET) scan of a 54-year-old man with malignant melanoma. Patient was injected intravenously with 600 MBq (16 mCi) of ^{18}F-deoxyglucose.
- The image demonstrates extensive metastatic disease with abnormalities throughout the axial and proximal appendicular skeleton, right and left lungs, liver, and left inguinal and femoral lymph nodes.
- PET has applications in functional brain and cardiac imaging and is rapidly becoming a routine diagnostic tool in the staging of many cancers.

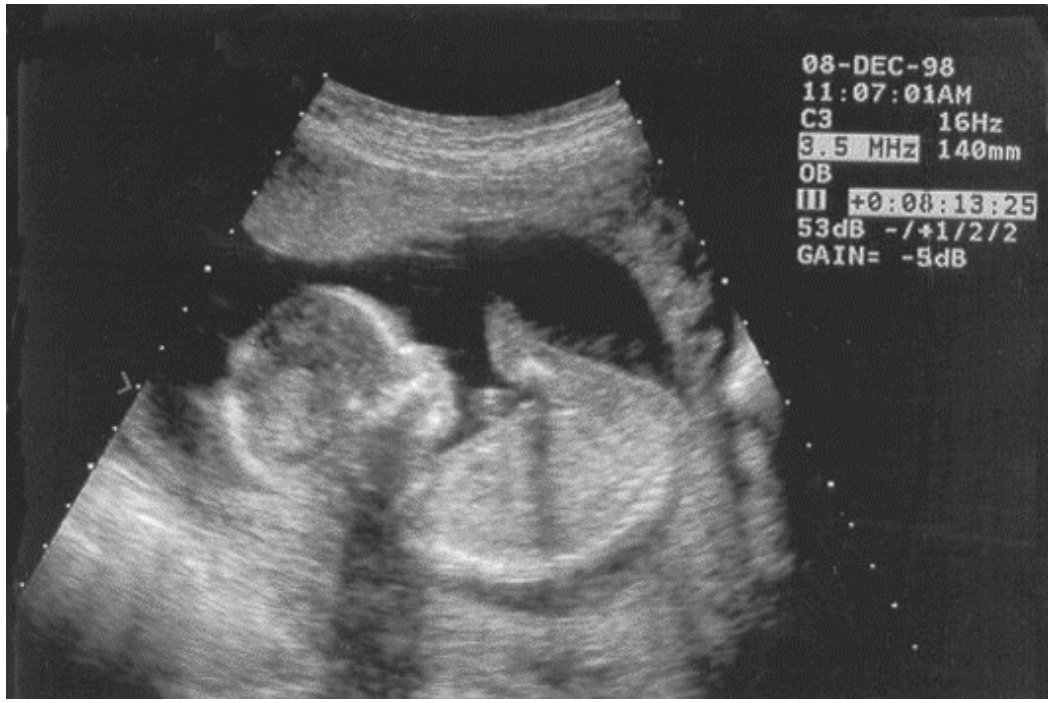
MRI



J.T. Bushberg, J.A. Seibert, E.M. Leidholdt, Jr., J.M. Boone, *The Essential Physics of Medical Imaging,2002*

- These are sagittal (upper left), coronal (lower left), and axial (right) normal images of the brain
- Upper images are T1-weighted, lower images are T2 weighted.
- MRI is widely used for anatomic as well as physiologic and functional imaging, and is the modality of choice for neurologic assessment, staging of cancer, and physiologic/anatomic evaluation of extremities and joints.

Ultrasound



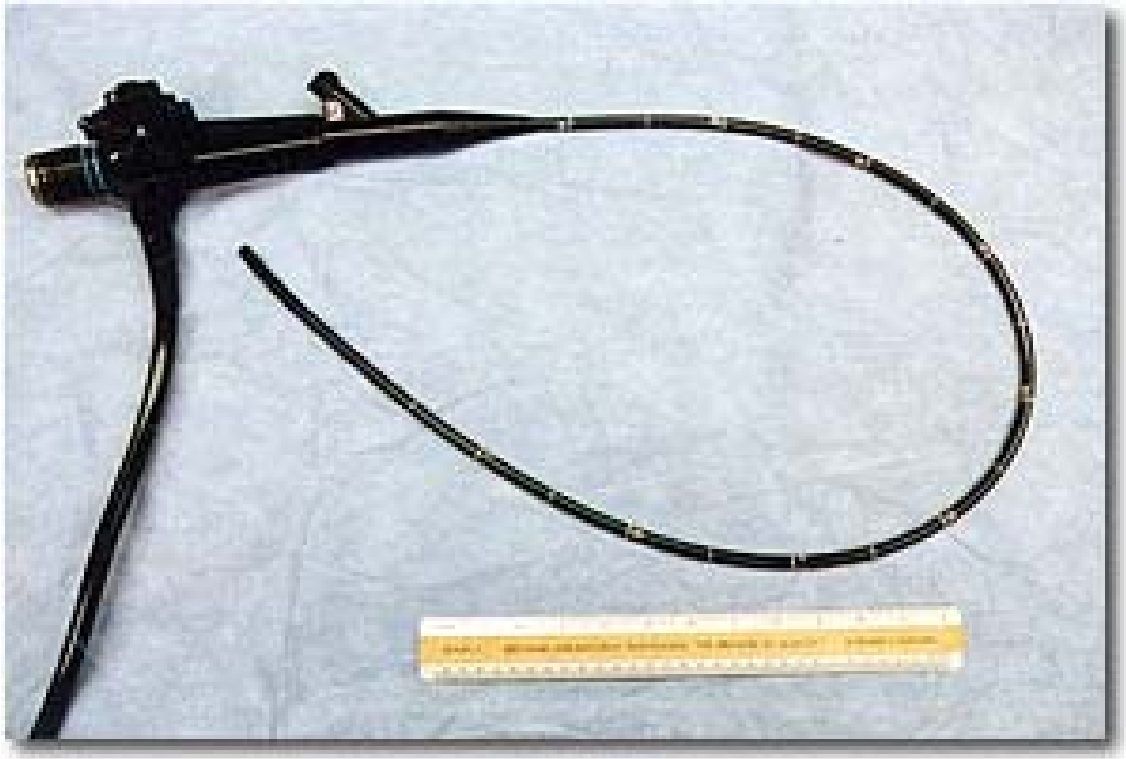
J.T. Bushberg, J.A. Seibert, E.M. Leidholdt, Jr., J.M. Boone, *The Essential Physics of Medical Imaging,2002*

- The ultrasound image is a map of the echoes from tissue boundaries of high-frequency sound wave pulses gray-scale encoded into a two-dimensional tomographic image.
- A phased-array transducer operating at 3.5 MHz produced this normal obstetrical ultrasound image.
- Increased use of ultrasound is due to low equipment cost, portability, high safety, and minimal risk.

12.2 Some Other Medical Imaging Modalities

(1) Endoscopy

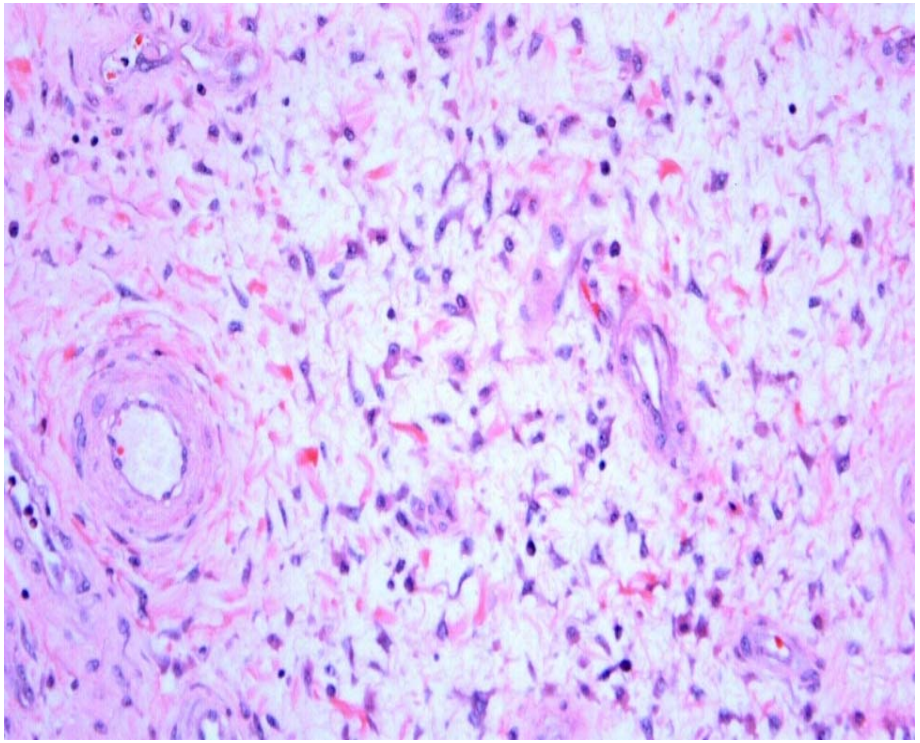
- Physicians had long used rigid tubes, mirrors, to peer down the throat and along other bodily passageways.
- The introduction of fiber optics in the 1950s makes endoscope a major clinical tool.



- Clinical applications of endoscopes have become highly specialized, such as examinations of:
  - The air passages;
  - The esophagus;
  - Stomach;
  - The colon.

- Endoscopes may have channels to convey gases or liquids in or out,
- Endoscopes may be equipped with a mechanical device such as a biopsy forceps.

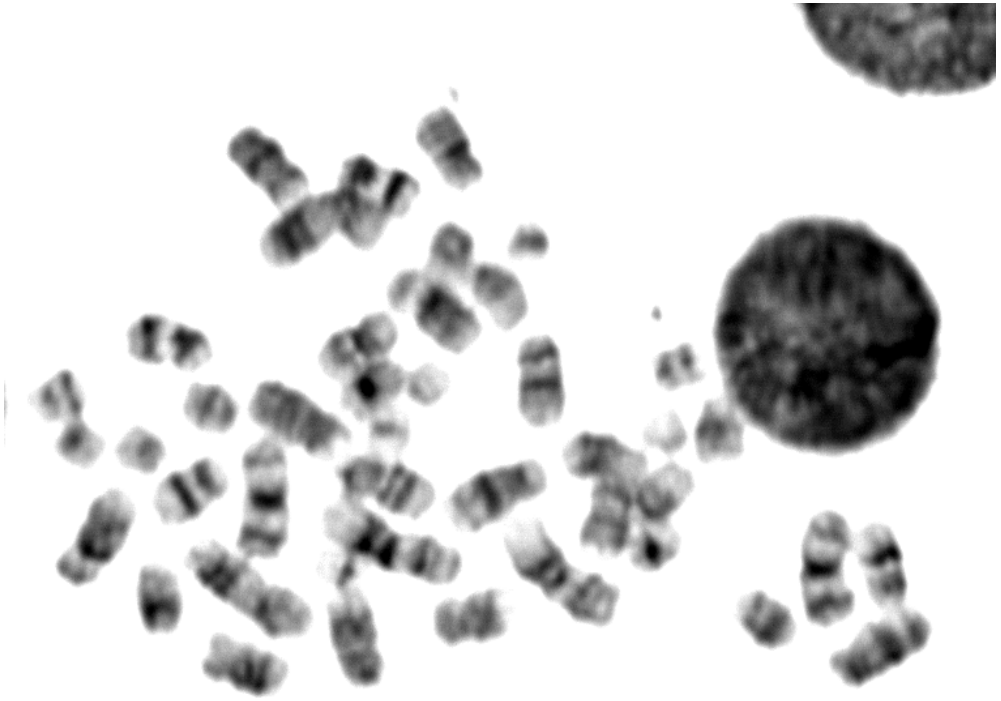
(2) Microscopic imaging in pathology



Courtesy: Dr. S. Li, Cytogenetic Lab, OUHSC

This is a pathological image of stained tissues sample, acquired by microscope. The areas show mixture of fat tissue and fibrous tissue.

Metaphase cells captured by scanning microscopic system



- Bone marrow slide, ×100 objective lens,
- Features dimensions are about 10-15µm long, 2-3µm wide,
- The bands can be as narrow as 0.5µm

12.3 PACS and Teleradiology

(1) Introduction

- Digital imaging technology and computer networks, workstations, storage devices and media, and display devices have spurred the implementation of picture archiving and communications systems **(PACS)** and teleradiology.
- The goal is to improve the utilization and efficiency of radiological imaging.
- For example, a PACS can replicate images at different display workstations simultaneously for the radiologist and referring physician, and be a repository for several years' images.
- The transfer of images via teleradiology can bring subspecialty expertise to rural areas and permit prompt interpretation of studies, particularly in trauma and other urgent cases.

(2) PACS

- A **PACS** is a system for the storage, transfer, and display of radiological images.

Picture — captures the image.

- Instead of being printed on film, the captured images are sent directly from the diagnostic imaging modality to your PACS.

Archive — stores the image.

- Images are now permanently stored in an electronic archive.

Communication — distributes the image.

- This aspect includes how the images are viewed throughout the hospital on both diagnostic and clinical workstations as well as how the images are made available to the referring community.

System — manages the integration and interface to other clinical systems.

Components of a PACS

- A PACS consists of a digital archive to store medical images, display workstations to permit physicians to view the images, and a computer network to transfer images and related information.
- There also must be a database program to track the locations of images and related information in the archive and software to permit interpreting, and perhaps referring, physicians to select and manipulate images.
- For efficiency of workflow and avoidance of errors, the PACS should exchange information with other information systems, such as the hospital information system (HIS), radiology information system (RIS), and electronic medical record (EMR) system.

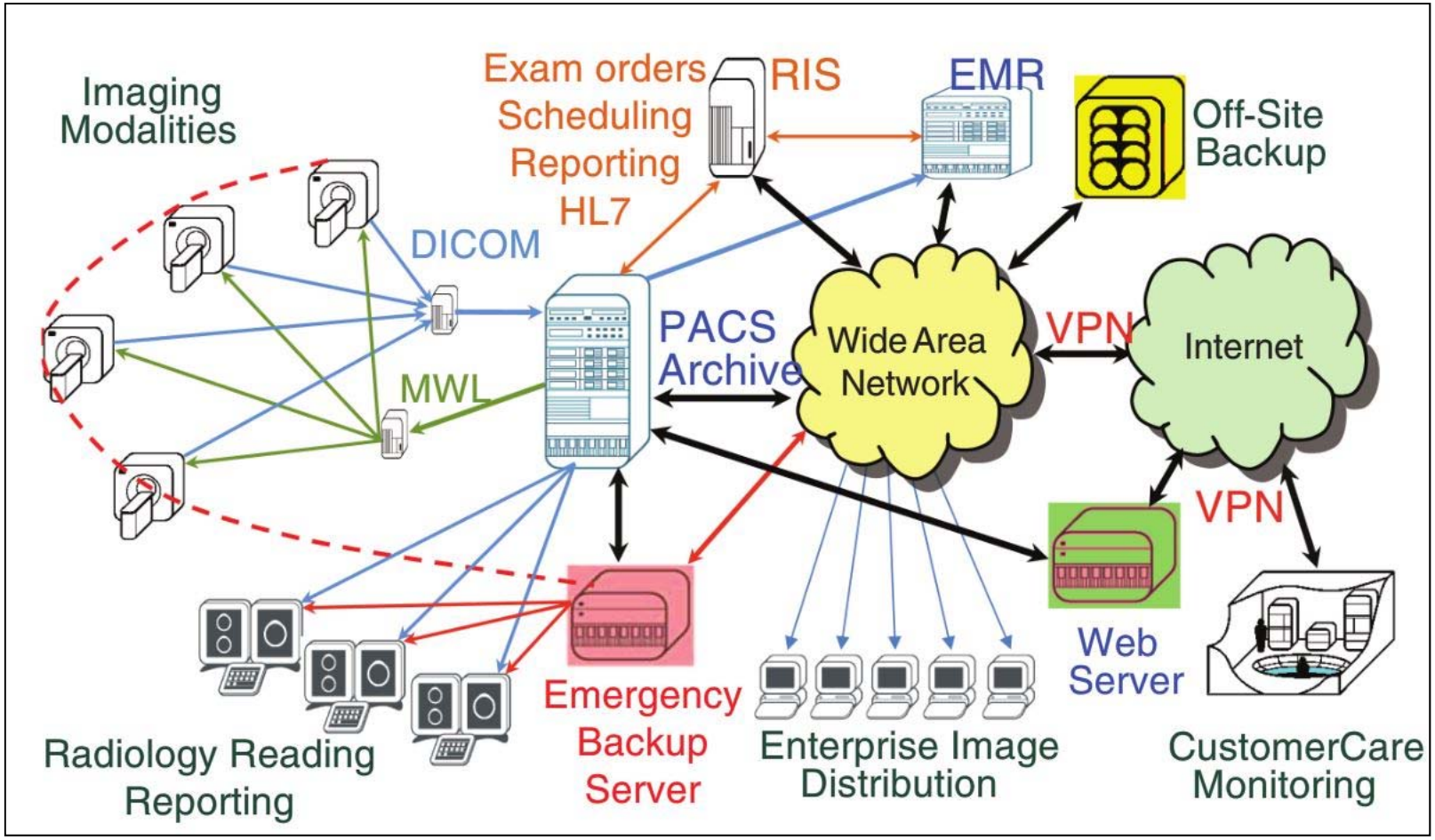


Figure: Modern PACS uses a webserver connected to the internet and a thin client paradigm to allow referring clinicians without access to the medical enterprise network to obtain images and reports. Users within the medical enterprise have access through a local area network (LAN) and wide area network (WAN).

HL7: Health Level 7 (a standard for the exchange of data with hospital information system); **MWL**: modality worklist; **HIS**: hospital information system; **RIS**: radiology information system; **EMR**: electronic medical record system; **VPN**: virtual private network

PACS vary widely in size and in scope.

- A PACS may be devoted to only a single modality at a medical facility.
  - In this case, the entire PACS may be connected by a single LAN. Such a small, single-modality PACS is sometimes called **mini-PACS.**

- A PACS may incorporate all imaging modalities in a system of several medical centers and affiliated clinics.
  - In these cases, the PACS is likely to exist on an extended LAN or on a WAN constructed from multiple LANs.

Acquisition of digital images

In many modalities, the imaging devices themselves produce digital images, such as:

- CT
- MRI
- Digital radiography
- Digital fluoroscopy
- Ultrasound
- Nuclear medicine

Storage of images

The amount of storage required by a PACS archive depends upon the modality or modalities served by the PACS, on the workload, and the storage duration.

(a) Storage schemes

- In a PACS, a hierarchical storage scheme has been commonly used, with recent images available on arrays of magnetic hard disks and with a culling and transfer of older images to slower but more capacious archival storage media.
- The amount of storage necessary depends on the modality or modalities served by the PACS and on the work load.

(b) Image management

- The PACS archive may be centralized, or it may be distributed, that is, stored at several locations on a network.
- In either case, there must be archive management software on a server.
- The archive management software communicates over the network with imaging devices.
- The archive management software must also obtain studies from the storage devices and send either the studies or selected images for display.

Display of images

- Images from a PACS may be displayed on monitors or, less often, may be recorded by a laser imager on light-sensitive film, which is chemically developed, and then viewed on light boxes.
- The purpose of the display system is to present anatomic and/or physiologic information in the form, of images to interpreting physicians and other clinicians.
- Computer workstations equipped with display monitors are commonly used, instead of viewboxes and photographic film, to display radiological images for both interpretation and review.

Display workstations

- An interpretation workstation for large matrix images (digital radiographs, including mammograms) is commonly equipped with two high-luminance 3 or 5 megapixel grayscale monitors, in the portrait orientation, to permit the simultaneous comparison of two images in near full spatial resolution.

Figure: Interpretation workstation containing two 1.5 by 2 k pixel (3 megapixel) portrait-format grayscale monitors for high resolution and high luminance image interpretation, flanked by two 1.9 by 1 k (2 megapixel MP) color “navigation” monitors (left and right) for PACS access.

- Workstations for viewing CT and MRI images, fluorographys, and angiographic images can have smaller pixel format monitors.
- If surface or volume rendered images or co-registered PET/CT or SPECT/CT images are to be displayed, the workstation should be equipped with high-luminance color monitors.
- Workstations for interpretation of angiographic image sequences (e.g., cardiac angiograms and ventriculograms and digital subtraction angiograms) should be capable of displaying cine images (sequences of images acquired to depict temporal variations in anatomy or contrast material).
- Workstations for the interpretation of nuclear medicine and ultrasound images should have color monitors and must be able to display cine images.

Digital imaging and communications in medicine (DICOM)

- The American College of Radiology and the National Electrical Manufacturers' Association jointly sponsor a set of standards called Digital Imaging and Communications in Medicine (**DICOM**) to facilitate the transfer of medical images and related information.
- DICOM includes standards for the transfer, using computer networks, of images and related information from individual patient studies between devices such as imaging devices and storage devices.
- DICOM specifies standard formats for the images and other information being transferred, services that one device can request from another, and messages between the devices.

DICOM file format

- DICOM specifies standard formats for information objects, such as "patients," "images," and "studies."
- These are combined into composite information objects, such as the DICOM CT (computed tomography) image object, CR (computed radiography) image object, DX (digital x-ray) image object, MG (digital mammography x-ray) image object, US (ultrasound) image object, MR (magnetic resonance imaging) image object, and NM (nuclear medicine) image object.
- DICOM specifies standard services that may be performed regarding these information objects, such as storage, query and retrieve, storage commitment, print management, and media storage.

- DICOM provides standards for workflow management, such as modality worklists (MWLs) listing patients to be imaged on specific imaging devices, and Performed Procedure Step, for communicating information about the status of a procedure.
- DICOM also provides standards, particularly Grayscale Standard Display Function (GSDF) and Presentation State, for the consistency and presentation of displayed and printed images.
- Details of the DICOM specification are available at the NEMA site, (http://medical.nema.org), and many public domain and open source implementations exist.

(3) Teleradiology

- Teleradiology is the transmission of radiologic images for viewing at a site or sites remote from where they are acquired.
- Teleradiology can provide improved access to radiology for small medical facilities and improved access to specialty radiologists.
- PACS and teleradiology are not mutually exclusive. Many PACS incorporate teleradiology.
- It is essential that PACS and teleradiology systems provide images suitable for the task of the viewer.
- When the viewer is the interpreting physician, the images viewed must not be significantly degraded in either contrast or spatial resolution with regard to the acquired images.

(4) Security issues of PACS and teleradiology

- An important issue regarding medical imaging, PACS, and teleradiology is information security.
- The main goals of information security are (1) privacy, (2) integrity, (3) authentication, (4) nonrepudiation, and (5) availability.
  - **Privacy**, also called confidentiality, refers to denying persons, other than intended recipients, access to confidential information.
  - **Integrity** means that information has not been altered, either accidentally or deliberately.
  - **Authentication** permits the recipient of information to verify the identity of the sender and the sender to verify the identity of the intended recipient.
  - **Nonrepudiation** prevents a person from later denying an action, such as approval of a payment or approval of a report.
  - **Availability** means that information and services are available when needed.

- The Federal Health Insurance Portability and Accountability Act of 1996 (**HIPAA**) and associated federal regulations (45 CFR 164) impose security requirements for “electronic protected healthcare information.”
- Goals of the HIPAA regulations are to:
  - Ensure the confidentiality, integrity, and availability of all electronic protected healthcare information
  - Identify and protect against reasonably anticipated threats or hazards to the security or integrity of the information
  - Protect against reasonably anticipated impermissible uses or disclosures
  - Ensure compliance by the workforce.

- Security measures include administrative, physical, and technical safeguards.
- The following is a list of elements in a PACS and teleradiology security plan:

1. Perform a risk analysis.
2. Establish written policies and procedures for information security.
3. Train staff in the policies and procedures.
4. Backups—Maintain copies of important programs and information in case the data on a single device are lost. Backup copies should be stored in a secure location remote from the primary storage.
5. Install commercial antivirus software on all computers to identify and remove common viruses and periodically update the software to recognize the signatures of recent viruses.

6. Forbid the loading of removable media and programs from nontrustworthy sources and forbid activating attachments to unexpected e-mail messages.
7. Authenticate users, directly and over a network or a modem, by passwords.
8. Terminate promptly the access privileges of former employees.
9. “Log off” workstations, particularly those in nonsecure areas, when not in use.
10. Grant each user only sufficient privileges required to accomplish needed tasks and only access to information to which the user requires access.
11. Secure transfer—Encrypt information transferred over nonsecure networks.

12. Secure storage—physically secure media or encrypt the information on it.
13. Erase information on or destroy removable media and storage devices before disposal or transfer for reuse.
14. Install “patches” to the operating system to fix security vulnerabilities.
15. Install “firewalls” at nodes where your LAN is connected to other networks.
16. Audit trails—Each access to protected healthcare information must be recorded.
17. Establish an emergency operations and disaster recovery plan.

Summary:

1) The principle and clinical applications of major medical imaging modalities such as Projection Radiography, Fluoroscopy, Computed Tomography, Nuclear Medicine, MRI and Ultrasound.
2) Other medical imaging techniques, such as endoscopy and microscopic imaging in pathology
3) PACS: Picture Archiving and Communications Systems
4) DICOM: Digital Imaging and Communications in Medicine.
5) Teleradiology: transmission of radiologic images for viewing at a site or sites remote from where they are acquired.
6) Security: the main goals of information security regarding medical imaging, PACS, and teleradiology are (a) privacy, (b) integrity, (c) authentication, (d) nonrepudiation, and (e) availability.

Homework #11

1) You need to acquire an x-ray image of a small animal for one of your research projects. Because of the specific requirements of your experiments, a spatial resolution of 25 *lp/mm* or higher is needed. Indeed the spatial resolution is the most important requirement of this experiment. What x-ray imaging modality would you use?

2) What is PACS (the definition of PACS)? What are the key components of a mini-PACS system?

3) What is DICOM (the definition of DICOM)?

4) Please describe the most important difference of projection radiography and X-ray CT.

5) A clinician needs to select an imaging modality to guide a surgical procedure in real time. Suppose all of the following imaging modalities, MRI, CT, Project Radiography, Fluoroscopy and Ultrasound, can provide clear images for the specific region-tumor of the patient. Which modality would the clinician select? Why?